CANADA – NOVA SCOTIA
FLOOD DAMAGE REDUCTION PROGRAM

June 1983

HYDROTECHNICAL STUDY OF THE ANTIGONISH AREA FLOOD PLAIN

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10 August 1983

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Attention: Mr. H.T. Doane, P. Eng
Program Manager

Dear Mr. Doane:

Antigonish Hydrotechnical Study

We are pleased to submit our final report concerning the Antigonish Hydrotechnical Study. Your comments concerning the earlier draft versions have been incorporated.

The methodology and findings of our investigations are presented in the enclosed report.

We would like to express our sincere appreciation to the members of the Flood Risk Technical Committee for their co-operation and assistance throughout the course of this study. All of which is respectfully submitted.

Yours very truly,

MacLAREN PLANSEARCH INC.

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Project Manager

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CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

HYDROTECHNICAL STUDY FOR

ANTIGONISH AREA FLOOD PLAIN

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FOREWORD

This report was written by M.D. Conetta, P.Eng. and D.B. Hodgins, P.Eng., Water Resources Division, with contributions from H.S. Belore, P.Eng. and J.F. Burrows, P.Eng. formerly with MacLaren Plansearch.

The information presented in this report was derived with the kind cooperation and assistance of several individuals. Invaluable comments and direction were provided by the following members of the Canada-Nova Scotia Flood Risk Mapping Technical Committee:

- H.T. Doane; P.Eng., Program Manager, Flood Damage Reduction Program.

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- L.R. Lewis; P.Eng., Chief, Water Management Section, Nova Scotia Department of the Environment.

- D.E. English; Coordinator, Community Planning Division, Nova Scotia Department of Municipal Affairs.

- E.R. Langley; P.Eng., Flood Studies Engineer, Water Planning and Management Branch, Inland Waters Directorate, Environment Canada.

The writers would also like to express their appreciation to Dr. B.V. Liengme of Antigonish who volunteered to oversee the operation of the raingauge located on his property.

The background data presented in this report was obtained from several sources including the Inland Water Directorate and the Atmospheric Environment Service of Environment Canada and the Marine Environmental Data Service of Fisheries and Oceans Canada. Background information was obtained from CNR, Nova Scotia Department of Transportation and the Maritime Resource Management Service. The staff of MacLaren Plansearch was assisted in undertaking various field surveys by the firm of C.J. MacLellan and Associates Limited, Antigonish.

Finally, we would like to express our appreciation for the time and effort of all those who contributed to this project by way of information, discussions and otherwise.

CHAPTER 1 - SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1.1 Summary

Introduction

The Town of Antigonish has been subjected to flooding from the West and Rights Rivers and Brierly Brook. Flooding has been caused in the past by heavy rainfall, rainfall-and-snow-melt and ice jams. Because of the damages and the potential danger to lives that these floods have created, a flood risk mapping study has been undertaken under the Canada - Nova Scotia Flood Damage Reduction Program.

The main purpose of this study is to identify and delineate flood hazard areas within the Town of Antigonish and adjacent areas of Antigonish County. Water surface profiles corresponding to specified probabilities (1:20 and 1:100 year in this study) were used as the basis for delineating the flood hazard areas on specially prepared maps. Once the flood hazard areas are delineated, they may be designated and there only certain conforming developments should take place. These maps then serve as a means of informing the public, government agencies, private companies, etc. of the flood hazard.

This report, along with the flood risk mapping, gives the results of the study undertaken.

A summary of the major aspects of this study follows:

Background Information

As part of this study, an in-depth review of background information was undertaken to identify historical flood prone areas, reasons for the occurrence of flooding and remedial measures that had been proposed or carried out to alleviate the flooding problems. It was found that in general there are three areas (see Figure 5-1) subject to flooding in Antigonish, identified as follows:

1. Properties between St. Ninian and Main Streets where flooding is caused primarily by Brierly Brook.

2. Land behind Arbour Drive where flooding is caused by the Rights River.

3. In the vicinity of Columbus Field and St. Andrews Street where flooding is caused by Brierly Brook and the West River.

Flooding has been caused by hydrologic and climatic factors as well as man-made changes in the flood plain which have aggravated the flooding problems. Several engineering studies have been undertaken to examine remedial measures to alleviate flooding in Antigonish. These proposals range from building flood retardation dams at upstream sites to the implementation of flood and erosion control works along specific reaches of the streams. As a result of these investigations, three major flood control works have been undertaken in the area which have tended to improve the flooding situation.

These works are:

1. The construction of the Brierly Brook dam in 1976.

2. The channel realignment and straightening of the Rights River near Cloverville Road.

3. The replacement of the McAmis bridge with a single span structure at St. Andrews Street across the West River.

Field Monitoring Program

A field monitoring program was conducted from November 1980 to the end of May 1982 to collect rainfall, water level and discharge data. This program was initiated to obtain data for the calibration and validation of the hydrologic and hydraulic models. Staff gauges and crest gauges were installed at bridge structures throughout the study area to obtain peak water levels during storm events. Furthermore a number of flow metering stations were also established to obtain stream flows during storm events. The location of the staff gauges, crest gauges and flow metering stations are shown in Figure 5-1.

A recording tipping bucket raingauge was also installed near Somers Road in the Brierly Brook watershed. Its location is shown in Figure 5-1. A local observer from the Town of Antigonish monitored rainfall and water level conditions in the Antigonish area streams. When water levels exceeded prescribed elevations, flow metering was initiated with the assistance of personnel from the MacLaren office in Halifax.

Ice conditions during break-up were monitored during the 1980-81 and 1981-82 winter periods within the study reaches. The ice related information was then used to define an appropriate technique for ice jam modelling.

Hydrologic Analysis

The single event hydrologic simulation model, HYMO, was applied to the Brierly Brook and Rights River watersheds. Although hydrologic simulations were initially to be undertaken only for the Brierly Brook watershed, it was found necessary to carry out hydrologic simulations for the Rights River due to the lack of calibration data for Brierly Brook. Calibration results from the Rights River watershed were then used to calibrate the Brierly Brook hydrologic model. The HYMO models were calibrated and validated based on data collected from the field monitoring program and supplemented where possible with data from adjoining watersheds.

Rainfall intensity-duration-frequency (IDF) data derived from records of the climatological station at Truro were used due to the lack of such data in the Antigonish area. As a result of the hydrologic simulations carried out, it was found that the 6-hour storm is the critical storm duration for both the Brierly Brook and Rights River watersheds. It was also found that the annual IDF curve produces higher peak flows than the rainfall-and-snowmelt event (April). It consequently was adopted as the governing design condition.

Peak flow simulations were carried out for Brierly Brook, with and without the effect of the Brierly Brook dam to establish the 1:20 year and 1:100 year design flows. Design

flows for the Rights River and the West River were derived from the Regional Flood Frequency Analysis (Ref. 14). Sensitivity testing of the hydrologic model was also undertaken.

Conditions leading to ice jams were investigated through the analysis of historical ice jams and the ice jams observed during the winters of 1981 and 1982.

Hydraulic Analysis

The HEC-2 hydraulic model was used to compute the 1:20 and 1:100 year return period flood elevations under open water conditions. Peak flows for Brierly Brook, Rights River and West River derived as described above were used in the HEC-2 hydraulic models to compute the design water surface elevations. For open water conditions the models were calibrated based on the peak high water levels observed during a storm event which occurred in November 1981. Due to the non-occurrence of high flow events during the field monitoring period, it was not possible to obtain peak water levels to validate the hydraulic models. In order to make use of all available information, it was decided to use the high water levels observed during Hurricane Beth in 1971 to confirm the calibration results. The Hurricane Beth peak flows simulated for Brierly Brook and the Rights River were used as input to the hydraulic models. Hydrologic simulations of the West River watershed were not part of the study so hydraulic simulations were carried out for the West River to obtain the Hurricane Beth peak flow. Various flow conditions were used to obtain the water surface profile that was consistent with the observed high water levels during Hurricane Beth.

For ice conditions, the HEC-2 Ice option of the program was used to calibrate the model based on ice jams that occurred during the winters of 1981 and 1982. The results of the calibration exercises were used as the basis to compute the flood levels due to ice jam conditions.

Sensitivity testing of various hydraulic parameters was also carried out. The parameters changed in the computer modelling were: flow, starting water depth, roughness coefficient (Manning's n) and the expansion and contraction coefficients. Each of the parameters above was varied by ±10% while holding the other parameters fixed.

Remedial measures to alleviate flood damage are also suggested for the Antigonish area.

1.2 Flood Hazard Areas

The governing 1:20 and 1:100 year water surface profiles were plotted on 1:2000 scale topographic maps to delineate the flood hazard areas susceptible to flooding. The following areas are susceptible to flooding:

i) The lower reaches of the Rights and West Rivers downstream of St. Andrews Street. Low lying area between the two rivers is flooded both by the 1:20 and 1:100 year water surface profiles.

ii) Area upstream of St. Andrews Street and Main Street near Columbus Field inundated by both the 1:20 and 1:100 year water surface profiles from the flow of the West and Rights Rivers.

iii) Area at the confluence of Brierly Brook and the West River. Backwater effect from the West River extends upstream of Church Street.

iv) Antigonish Mall flooded by the 1:100 year West River water surface profile to a depth of about 0.5 m (1.6 feet). Areas surrounding the Mall are also flooded by the 1:20 year water levels.

v) Residential area to the north-east of the intersection of Brookland Street and MacLellan Street upstream of Cloverville Road inundated by the Rights River 1:100 year water surface profile.

1.3 Conclusions

i) Open water flooding due to extremely high flows was investigated. Flood levels due to 1:100 year and 1:20 year flows were calculated. Ice jam flooding was also investigated and compared with open water flow levels. Examination of water levels due to ice jams which have occurred recently indicated localized water levels greater than 1:100 year expectation flows would be produced. For this reason and due to the element of uncertainty and statistical probability relating to flow figures, the upper 95% confidence limit flows for the 1:20 year and 1:100 year floods have been used to define the floodway and floodway fringe areas respectively.

ii) Flows to Brierly Brook are regulated by the dam. For flows anticipated to recur on average once in 100 years there will not be overtopping of the dam and uncontrolled discharge of stored water. The flood control

effect of the Brierly Brook Dam is most pronounced at low flows that occur more frequently. Blockage of the low level outlet of the dam was investigated. This revealed that the 1:100 year peak flow would be greater than otherwise. For lower flows however (1:20 year flow) blockage would reduce peak flow rates, and thus water levels downstream. (This may suggest an operable gate on the low level outlet might make it possible to further reduce flooding adjacent to Brierly Brook).

iii) Tides affect the lowest reaches of Rights and West Rivers since these discharge in the tidal flats. Thus extreme tides define the flood risk area below the CNR track. The effects of tide diminishes and becomes negligible upstream of the Main Street Bridge across the Rights River and the McAmis Bridge across the West River.

iv) Erosion damage can be expected as a result of high flow velocities in the St. Andrews and Main Street areas.

v) The average return period for Hurricane Beth, experienced in 1971, has been estimated to be greater than 100 years.

vi) Rights River diversion channel appears to reduce the extent of flooding in the vicinity of Cloverville Road.

vii) The remedial measures that might be investigated in order to reduce flood damages are as follows:

- Ice jams on Brierly Brook in the vicinity of Church Street,

- channel modification to allow ice and water to spill easily into the floodplain upstream of the bridge

- breaking of ice sheet from Church Street to Main Street prior to an increase in flow

- the construction of additional culverts across Church Street to bypass flood flows to the lower channel

- reconstruction of the Church Street Bridge

- enlargement of the Church Street Bridge.

- Ice jams on Rights River in the vicinity of Main Street,

  - breaking of ice sheet upstream and downstream of the Main Street Bridge

  - flood proofing of several structures along Elm Street

  - flood proofing Main Street at Elm Street to keep the street open to traffic.

- The construction of flood retardation dams on the West and Rights Rivers upstream of the Town of Antigonish.

- Localized berming or flood proofing of flood prone structures located upstream of Main Street and Cloverville Road due to the flooding from the Rights River; localized berming or flood proofing of the flood prone structures located upstream and downstream of Church Street due to flooding from the West River.

- Acquisition of flood prone property and dedication to uses immune to flood damage.

- Enforcement of floodplain uses regulations.

1.4 RECOMMENDATIONS

It is recommended that:

i) A tipping bucket rain gauge to obtain rainfall intensity duration data be installed to enable the refining of the hydraulic models.

ii) A stream gauge on the West River be installed in order to refine the modelling and design data for hydraulic structures in the area.

iii) A recording gauge on the Brierly Brook Dam be installed to further ensure the safety of the dam and provide additional hydraulic information.

iv) Inspection and maintenance of the Brierly Brook Dam be carried out to ensure the safety and performance of the structure for flood control purposes.

vi) Remedial measures to reduce erosion damage at anticipated areas be investigated.

vii) Remedial measures to reduce flooding frequency and severity be undertaken to reduce flood damages and alleviate potential danger to lives.

viii) Land use regulations for the use of floodplain lands be considered for both appropriate purposes such as recreation and inapproprite ones such as businesses and institutions.

ix) Contingency plans to respond to flooding be prepared and rehearsed.

x) Public, as well as institutions, be made aware of the potential risk associated with flood hazard areas.

CHAPTER 2 - INTRODUCTION

2.1 General

The study area is located on the north coast of Nova Scotia, just west of the Strait of Canso on St. Georges Bay as indicated on Figure 2-1. The Town of Antigonish, which is located approximately halfway between New Glasgow and Port Hawkesbury, is situated within the study area. The total areal extent of the Town of Antigonish is approximately 405 hectares (1000 acres), of which about 120 - 160 hectares (300-400 acres) remain to be developed. However, according to the Town's Municipal Development Plan (Ref. 9) much of the undeveloped land is considered as susceptible to frequent flooding.

The Town of Antigonish is situated at the confluence of three rivers, namely Brierly Brook, West River and Rights River. Since its early beginnings in 1786, the historical development of Antigonish in flood prone lands has led to a potential for future flood losses in the Town. The existing land use in the study reach has been identified by the Town's Municipal Development Plan (Ref. 9) as being primarily residential, industrial and institutional. One of the major land uses is St. Francis Xavier University which was founded in 1853. It is also the main employer in the Town. The population of the Town of Antigonish is presently between 5000-6000 people, with additional seasonal influxes of between 2000-3000 students. Recent studies (Ref. 7) have estimated that the Town could expand to more than 12 000 people by the year 2000. This could result in increased pressures for utilizing lands which are frequently flooded and hence could further increase the potential for flood damages.

In this regard, the Province of Nova Scotia and the Government of Canada have entered into a "General Agreement Respecting Flood Damage Reduction", with the objective of reducing potential flood damages on flood plains along the shores of lakes, rivers and the sea. This agreement recognizes that the potential for flood damages can be reduced by control of the uses made of flood hazard areas. This involves the identification and delineation of flood prone areas and ultimately the designation of these areas wherein only certain conforming developments could take place. As part of this initiative, a flood hazard mapping program is being undertaken in Nova Scotia. The mapping of a flood hazard area consists of four main components: hydrology, hydraulics, topographic mapping and public information. The main purpose of this investigation is to provide the hydrologic and hydraulic components for the identification of flood hazard lands in the Antigonish area.

The output from the hydrologic component, in the form of flood flows for specified probabilities, serves as the major input to the hydraulic component which will define the response of the river reaches under consideration to the hydrologic input and other relevant factors. The output from the hydraulic studies in the form of water surface profiles for the 1:20 and 1:100 year recurrence interval floods, is applied to specially prepared topographic maps to delineate the areal extent of these flood levels on the flood plain. The final component involves the development of maps, brochures and other interpretative information for the purpose of informing the public, government agencies, private companies, etc. of the flood hazard.

This hydrotechnical study of the Antigonish flood prone area has been carried out according to the guidelines for "Hydrologic and Hydraulic Procedures for Flood Plain Delineation" (Ref. 13) and under the guidance of the Flood Risk Mapping Technical Committee.

2.2 Climate

Flooding in the study area is a function of several climatic and topographic factors. The region has a modified continental climate, with a general movement of air masses from the west. The average annual wind speed in the Antigonish area is about 14-16 kilometres (9-10 miles) per hour from a westerly direction. Influxes of moist Atlantic air may produce mild spells in winter and cool weather during the summer and can result in the occurrence of severe storms at nearly any time of the year.

The annual precipitation in the Antigonish area is about 1200 mm per year (47.2 inches). Of the total precipitation, most falls as rain during the period of June to September, while about 180-200 mm (7-8 inches) of water equivalent snow occurs in the period from December to March. However, the mild winters produce frequent winter melt periods which reduce the total snow on the ground at the end of the winter to about 50-160 mm (2-6 inches) water equivalent at the end of March, varying according to location. For example, the Brierly Brook and Rights River watersheds generally have an average of about 100 mm (4 inches) of water equivalent snow on the ground at the end of March, while the West River has an average of about 160 mm (6 inches)(Ref. 14). The monthly distribution of precipitation is fairly even. Precipitation occurs in about 170 days per year.

The mean annual daily temperature for the region is about 5°C (41°F). Mean monthly temperatures for long term climatological stations in the area are presented in Table 7, following page 4-1. Freeze-up normally occurs in early December and ends in mid-April with one or two thawing periods during this time.

The rate of rainfall is an important flood generating factor for small watersheds such as Brierly Brook. Previous studies (Ref. 14, 7) have determined that flood producing storms can occur at any time of the year in the study area. Table 1 shows a summary of the incidence of heavy rainfall amounts to 1971. This summary represents the latest storm analyses prepared by the Atmospheric Environment Service. Interpretation of the data in Table 1 indicates that heavy storms can occur in any month with some tendency to higher frequencies in the months of August, September and October.

Based on the South River streamflow records (Station Number 01DR001), a discharge of 25 mm (1 inch) runoff or 0.30 cubic metres per second per square kilometre (27 cubic feet per second per square mile) occurs in the order of once every year (Ref. 3).

2.3 Topography

2.3.1 Drainage Basin Topography

The limits of the drainage areas and the river profiles for the West and Rights Rivers and Brierly Brook are shown in Figure 2-2 and Figure 2-3, respectively. The physical characteristics of each drainage system are detailed below:

TABLE 1

SUMMARY OF HEAVY RAINFALL EVENTS
BETWEEN 1918 TO 1971 IN THE STUDY AREA

AES* Storm Code No.	Date	Storm Period Hours	Total Precipitation mm	(Inch)	
NS-1-18	Jan. 4. 1918	30	88.9	(3.5)	
NS-10-23	Oct. 1. 1923	24	127.0	(5.0)	
NS-8-24	Aug. 11-15, 1924	105	88.9	(3.5)	
NS-11-27	Nov. 5. 1927	36	101.6	(4.0)	
NS-9-29	Sep. 17-19, 1929	72	88.9	(3.5)	
NS-9-33	Sep. 8-11, 1933	48	88.9	(3.5)	
NS-10-33	Oct. 5-8, 1933	84	101.6	(4.0)	
NS-11-34	Nov. 4-7, 1934	60	101.6	(4.0)	
NS-1-35	Jan. 8-11, 1935	66	50.8	(2.0)	
NS-8-35	Aug. 22-25, 1935	90	139.7	(5.5)	
NS-9-36	Sep. 19, 1936	30	76.2	(3.0)	Hurricane
NS-11-37	Nov. 20, 1937	30	76.2	(3.0)	
NS-6-40	Jun. 19-20, 1940	90	63.5	(2.5)	
NS-9-42	Sep. 20-23, 1942	84	101.6	(4.0)	
NS-10-42	Oct. 24-27, 1942	72	76.2	(3.0)	
NS-7-43	Jul. 8, 1943	24	76.2	(3.0)	
NS-8-43	Aug. 3-5, 1943	54	50.8	(2.0)	
NS-9-46	Sep. 15, 1946	36	63.5	(2.5)	
NS-4-47	Apr. 30 - May 3, 1947	72	88.9	(3.5)	
NS-2-48	Feb. 14, 1948	24	76.2	(3.0)	
NS-8-49	Aug. 18-19, 1949	48	63.5	(2.5)	
NS-11-50	Nov. 27-30, 1950	84	88.9	(3.5)	
NS-1-56	Jan. 4-10, 1956	144	101.6	(4.0)	
NS-1(2)-56	Jan. 10-16, 1956	144	127.0	(5.0)	
NS-11-57	Nov. 1-4, 1957	66	101.6	(4.0)	
NS-6-59	Jun. 20, 1959	36	50.8	(2.0)	
NS-10-59	Oct. 23-28, 1959	90	50.8	(2.0)	
NS-10-61	Oct. 20-21, 1961	36	63.5	(2.5)	
NS-8-63	Aug. 24-25, 1963	48	63.5	(2.5)	
NS-6-64	Jun. 11-13, 1964	54	88.9	(3.5)	
NS-7-64	Jul. 3, 1964	96	63.5	(2.5)	
NS-8-64	Aug. 24, 1964	36	63.5	(2.5)	
NS-9-64	Sep. 14, 1964	24	76.2	(3.0)	Hurricane Ethel
NS-12-64	Dec. 25-29, 1964	96	64.5	(2.5)	
NS-8-65	Aug. 20, 1965	30	88.9	(3.5)	
NS-5-67	May 25-28, 1967	60	88.9	(3.5)	
NS-10-67	Oct. 9-11, 1967	66	88.9	(3.5)	
NS-8-68	Aug. 29-31, 1968	48	101.6	(4.0)	
NS-10-68	Oct. 20-21, 1968	42	50.8	(2.0)	
NS-8-71	Aug. 14-17, 1971	60	254.0	(10.0)	Hurricane Beth

Source: Ref. (18)

*AES - Atmospheric Environment Service

Rights River

The Rights River drains a watershed of about 129.2 square kilometres (49.4 square miles). It has its headwaters at Maple Ridge at an elevation of about 297 metres (975 feet). The length of the watercourse is about 21.7 kilometres (13.5 miles) with an average streambed gradient of about 13.7 metres/kilometre (72.2 feet/mile). Its major tributary is the South Rights River with a length of about 18.5 kilometres (11.5 miles) and an average gradient of 15.3 metres/kilometre (80.6 feet/mile). The upstream end of the study reach is located below the confluence of the Rights River flowing from the North and South Rights River flowing from the northwest. The western half of the watershed drains the Antigonish Highlands and the watershed is comprised of hilly terrain with elevations up to 320 metres (1050 feet). The land in the watershed is predominantly forest with some agriculture.

Based on hydrologic simulations carried out in Chapter 6, the estimated time to peak for the Rights River is about six to eight hours.

West River

The West River drains a watershed area of about 350 square kilometres (135 square miles) at McAmis Bridge. The watershed is characterized by very hilly terrain with elevations up to 300 metres (1000 feet).

The West River is fed by three major tributaries near Addington Forks, namely, the Ohio, James and Beaver Rivers. The lengths of these watercourses are 26.4 kilometres (16.4

miles), 17.7 kilometres (11.0 miles), and 14.5 kilometres (9.0 miles) respectively. In addition, the average streambed gradients for the rivers are 6.8 metres/kilometre (36.7 feet/mile), 14.8 metres/kilometre (78.2 feet/mile) and 14.5 metre/kilometre (76.7 feet/mile), respectively.

The West River follows a meandering course, from Addington Forks to the Antigonish Harbour. It is approximately 17.0 kilometres (10.5 miles) long with an average streambed gradient of 1.7 metres/kilometre (9.0 feet/mile). As shown in Figure 2-3, the West River is not as steep as the Rights River or Brierly Brook.

The land in the basin is predominantly forested.

Brierly Brook

Brierly Brook watershed drains an area of about 33.2 square kilometres (12.8 square miles). The predominant land uses in the watershed are agriculture and forestry. The topography can be characterized as hilly, with the elevations in the Pictou/Antigonish Highlands of the western portion of the basin being up to 300 metres (1000 feet). The easterly portion, or lowlands, range in elevation from sea level up to 200 m (650 ft).

Brierly Brook has its headwaters at Browns Mountain at an elevation of about 330 metres (1100 feet) and empties into the West River, a distance of about 17.4 kilometres (10.8 miles) downstream, within the Town of Antigonish. It has an overall average streambed gradient of about 17.5 metres/kilometre (92.6 feet/mile). However, it contains four dis-

tinct gradient regimes over its length. The upper 4.1 kilometres (2.5 miles) has a slope of 50 metres/kilometre (264.6 feet/mile); the next 2.8 kilometres (1.7 miles) has a slope of 5 metres/kilometre (26.5 feet/mile); the next 2.8 kilometres (1.7 miles) has a slope of 20 metres/kilometre (105.8 feet/mile) and the lower 7.9 kilometres (4.9 miles) has a slope of 4 metres/ kilometre (21.2 feet/mile) (Ref. 18).

Brierly Brook discharges are affected by the Brierly Brook dam. This flood control structure was constructed in 1976 downstream of Somers Road (refer to Figure 2-4) and regulates a drainage area of about 26.6 square kilometres (10.2 square miles) or about 80% of the watershed.

Based on hydrologic simulations carried out in Chapter 6 for this watershed, the time to peak under natural conditions is approximately four to five hours. However, due to the effect of the Brierly Brook reservoir, the time to peak at downstream locations within the town is delayed to nine to ten hours.

2.3.2 Study Area Topography

The Town of Antigonish is situated at the confluence of Brierly Brook and the West and Rights Rivers. The channel and floodplain of the West and Rights River through the Town are characterized by gentle slopes and gravelly channels. Elevations of the floodplain between the Town and the harbour vary from approximately 2.4 to 3.0 metres (8-10 ft) Geodetic Survey of Canada Datum (GSCD). In general, the edges of the river valleys in the study reach are well defined by steep slopes.

The West River shares a tidal estuary in Antigonish Harbour with the Rights River. The West River, from a location near the Antigonish Mall (refer to Figure 2-4) drops from elevation 1.4 to 0.82 metres (GSCD) (4.5 to 2.7 feet) at the mouth of Brierly Brook (streambed gradient of 2.2 m/km) over a distance of 262.1 metres (860 feet). Over the next 1280 metres (4200 feet) to the railroad trestle, the average bottom gradient is 0.30 metres in 231.6 metres (1 foot in 760 feet) (Ref. 16). In comparison, the drop in streambed elevation along the Rights River between Cloverville Road and Main Street is 2.9 metres in 860 metres (9.5 feet in 2820 feet) or a gradient of 3.37 m/km (17.8 feet/mile). Between Main Street and CNR bridge the Rights River drops 0.8 m in 790 metres (2.6 feet in 2590 feet) or a gradient of 1.0 m/km (5.3 feet/mile).

The bankful capacities for the three water courses were verified with the use of the HEC-2 hydraulic model set up for this study. A description of the model and its set-up for the Rights and West Rivers and Brierly Brook is given in Chapter 7.

The bankful capacity of the West River near the mall is estimated to be about 72.2 m^3/s (2550 cfs) and upstream of the St. Andrews Street (McAmis Bridge) it is 30-40 m^3/s (1060-1410 cfs). The bankful capacity of Brierly Brook is estimated to be 17.0-22.7 m^3/s (600-800 cfs) upstream from College Street (B-2) and 10-12 m^3/s (350-435 cfs) upstream of Church Street (B-1). The bankful capacity of the Rights River is approximately 140 to 150 m^3/s (4945 to 5300 cfs) in the vicinity of Main Street (R-2) and College Street (R-3). During the course of the study, it was possible to check the

channel capacity of the Rights River. A storm which occurred in November 1981 in the Antigonish area produced a flow which was almost to bankful capacity. The flow was modelled to be approximately 142 m^3/s (5015 cfs) using the hydrologic model described in Chapter 6.

2.4 Soils

A general description of the predominant soil classification for each watershed is outlined below.

Rights River

The predominant soil types in the Rights River basin are Thom (50%), Wolfville (35%) and Millbrook (15%). These soils exhibit moderate to medium runoff potential.

West River

Similarly, the predominant soil types in the West River are Thom (65%) and Wolfville (21%). The remainder consist of Herbert and Millbrook soil types. The predominant soils have similar runoff potential to those in the Rights River.

Brierly Brook

The soil types in the watershed are predominently Thom (51%) and Queens (31%). Other less significant soil types are Millbrook (8%), Stewiacke (5%) and Herbert (1%). Approximately three percent of the watershed is urbanized.

The predominant soil (Thom) is gravelly to sandy loam, generally exhibiting a moderate runoff potential. This till

material, 0.5 metre to 1 metre (1.5 feet to 3 feet) in depth, is underlain by igneous, metamorphic and sedimentary rocks. (Ref. 18)

2.5 The Flooding Problem

The three streams, the Rights River, Brierly Brook and the West River have all contributed to the historical flooding problems in the Antigonish area. While the history of flooding in the area is not particularly well documented, it is well known that frequent damage-producing floods have occurred. An historical summary of flood events is given in Table 2. Based on this and similar information, Environment Canada (Ref. 12) has identified 24 flooding incidents to 1978 in the study reach of which 6 were of damage producing significance. As indicated in Table 2, three other flooding events have occurred since 1978.

Most floods have occurred in the spring (March-April) as a result of rainfall and snowmelt events, or in the fall (August-September-October) as a result of rainfall events. The Municipal Development Plan adopted by the Town of Antigonish (Ref. 9) utilizes an historical flood event associated with the occurrence of Hurricane Beth in 1971 to define flood hazard areas within the town. It was estimated by the town that this event had a recurrence interval of approximately 1:50 year in the Antigonish floodplain (Ref. 5). The floodline based on the 1971 event is shown on Figure 2-4. These flood elevations were based on field measurements of water levels observed during the occurrence of this historical flood.

TABLE 2

HISTORICAL SUMMARY OF FLOODING IN ANTIGONISH

Date	Cause	Description/Location
March 1883	heavy rains	a 152 metre (500 foot) bridge crossing the intervale was damaged; at Barneys River, a 30 metre (100 foot) section of track was washed out
October 1923	tropical storm	concrete railroad bridge at James River was destroyed; Vinton's dam near Antigonish was partially destroyed; east end of Antigonish had lower grounds flooded to a depth of several feet; fair grounds were covered with water and a domestic service building was carried from its foundation; South River Rd. was reported to be impassable
Winter 1925	unknown	Section of Main St. inundated between Elm St. and Jocelyn Rd.; Webb's store on East Main St. inundated
November 1927	continuous rainfall for 24 hours	east end flooded; South River Road was covered with 1.2 metres to 1.5 metres (4 to 5 feet) of water; several cars stalled in feet) floodwaters between McAmis Bridge and the town
Fall 1928	unknown	an abutment of the West River bridge on St. Andrew's St. was washed out, four feet of water over fair grounds destroyed buildings and fences; Whidden's Intervale inundated
March 1930	torrential rains (48-hour period) ice jams	A Brierly Brook culvert caved in and as a result the brook tore its way through the roadbed
January 1935	high temperature torrential rains ice jam	streets covered with 1.2 to 1.5 metres (4 to 5 feet) of water; a number of houses on lower Main St. inundated. MacLellan's Mill inundated and a section of rail line nearby was washed out. Ice jam in West River resulted in powerline break
August 1935	heavy rains high tide	highway and grain crops were damaged; east end flooded by Rights River, West River and Brierly Brook

TABLE 2 (Cont'd)

HISTORICAL SUMMARY OF FLOODING IN ANTIGONISH

Date	Cause	Description/Location
November 1937	heavy rains (75 mm [3"] in 30-hour period)	the flood was reported to be of 'serious proportions'; a water main crossing a stream was reported to have broken after the water scoured and undercut it
August 1943	unknown	one foot of water reported over the road in front of Keltic Motors
January 1952	mild temperatures heavy rains ice jams	a couple of families forced to evacuate the ground floors of their homes; traffic was halted on Church Street
January 1956	snow rain high temperature	Church Court and St. Andrews Street all flooded and even Pleasant and Hawthorne were covered in water; Long Bridge on College Street was closed when centre abutment shifted; exhibition Grounds and Arena were inundated; Rights River washed out a cement dam which contained a watermain; power failures
Nov-Dec 1958	gale force wind and rain	rivers rose to freshet levels and water supplies in rural communities throughout Antigonish County were replenished
April 1964	heavy rains	Columbus Field was completely submerged; town parking lot was inundated
June 1964	heavy rains	Brierly Brook overtopped; grain fields were flooded at Arisaig
May 1967	heavy rainfall (60-hour duration)	West and Rights Rivers and Brierly Brook described at freshet levels; flooding reported on St. Ninian St. and bridge approach washed out.
August 1968	heavy rains	town parking lot and Columbus Field were inundated; bridge on Dunmore Road and one at St. Joseph's were washed out

TABLE 2 (Cont'd)

HISTORICAL SUMMARY OF FLOODING IN ANTOGINISH

Date	Cause	Description/Location
February 1971	heavy rains high temperature ice jams	town parking lot and a portion of Church Street were inundated; ice jam occurred at Church Street Bridge; residents of mobile homes on St. Ninian Street and tenants in the basement of Wong's property were flooded
August 1971	record rainfall Hurricane Beth	Hawthorne Street Bridge in western section was out; trailer courts in low lying areas evacuated; Columbus field inundated; floodwaters reported to have reached the 5 metre (16 foot) contour of the Antigonish Mall parking lot.
February 1973	mild temperature rain ice jams	some basements flooded; chunks of ice blocked streets when Brierly Brook overflowed
March 1973	mild temperature rain	ice jam at mouth of Brierly Brook
January 1976	heavy rains warm temperature ice jams	some residents were evacuated from an east end trailer court; businesses were inundated and an automobile dealer was forced to move his cars to higher ground
January 1978	heavy rain high winds	mobile homes overturned; power lines cut
January 1978	heavy rain	minor flooding reported throughout Antigonish Court; water covered 3.0 to 4.6 metres (10-15 feet) of parking lot behind 5 Cent to $1 store and Columbus Field for a short time as a result of ice jam in Brierly Brook.
February 1981*	rains high temperature ice jams	Brierly Brook overflowed its banks in the vicinity of Church Street due to an ice jam causing some basement flooding and also flooding the Co-op parking lot on Church Street (refer to Section 5.8 for detailed description of ice break-up in 1981)

TABLE 2 (Cont'd)

HISTORICAL SUMMARY OF FLOODING IN ANTOGINISH

Date	Cause	Description/Location
4-5 Feb. 1982*	high temperature rain ice jams	Ice blocked off the Main St. bridge across the Rights River cutting off the river's flow past this point. The flood waters flowed behind Keltic Motors and along Elm Street, across Columbus Field to the West River. Approximately 15 homes were flooded and travel along Main Street was curtailed for some 30 hours cutting off direct access to St. Martha's Hospital (refer to Section 5.8 for more detailed description of ice break-up in 1982)
10 March 1982*	high temperature rain ice jams	Ice jams caused the Rights River to overflow and cause flooding of the MacDonald's Trailer Court in the Brookland Street area. Some residents had to evacuate their homes and remove their parked cars

Source: Ref. (5)

* Flooding events observed as part of field monitoring program undertaken for this study from November 1980 to May 1982

While the West River has the largest drainage area, it has been the Brierly Brook watershed which has contributed most frequently to flooding problems in the study area. The Brierly Brook watershed is small and steep, resulting in flood peaks of a flashy nature. In addition, as shown in Figure 2-4, this watercourse bisects the built-up area of the town and many businesses and residences are located on its floodplain. In general, the areas (Refer to Figure 2-4) subjected to frequent flooding in Antigonish have been identified as follows:

1. Properties between St. Ninian and Main Streets where flooding is caused primarily by Brierly Brook.

2. Land north of Arbour Drive, which is sometimes referred to as the "Intervale", where flooding is caused by the Rights River.

3. In the vicinity of Columbus Field, located to the south-west of the intersection of Main St. and St. Andrews Street, and along St. Andrews Street where flooding is caused by Brierly Brook and the West River.

According to a survey conducted by Environment Canada some flooding occurs in the Columbus Field area up to four times a year as a result of mild weather, thawing, and ice jam problems. The frequency of flooding from the Rights River is thought to be about once every ten years (Ref. 5).

In addition to hydrologic and climatic factors, man-made changes in the floodplain have aggravated the flooding problems. The following changes have been identified (Ref. 5):

1. Construction of new commercial buildings along St. Andrews Street and an overall raising of the roadbed by about 1 metre, act as a dyke to flows carried by the West River and the discharge from Brierly Brook. (The elevated roadbed thereby tends to divert excess flows onto Columbus Field.)

2. Bridges across Brierly Brook at Braemore, Main, College, Church and the West River at St. Andrews Street (McAmis bridge) before replacement in 1976. In addition to creating backwater effects during peak flows, some of the bridges have contributed to ice jamming problems. (For example, the bridge on Church Street has frequently been cited as contributing to ice jamming problems.)

3. Increased building activity in the Town in recent years and related infilling of the floodplain.

4. Increased logging activities in some parts of the watersheds.

5. Construction of a sewage lagoon on the east bank of the Rights River downstream of Main Street with associated infilling of the floodplain.

6. Lands adjacent to the Rights River were subdivided and houses constructed near the "Intervale" (the area east and west of Arbour Drive).

7. Infilling of the West River floodplain during construction of the Antigonish Mall.

Other activities which have been carried out in recent years and which may have tended to mitigate flooding problems include the following:

1. The Rights River was relocated and straightened in the vicinity of the Cloverville Road area in 1972 after the occurrence of Hurricane Beth.

2. The Brierly Brook flood control dam was constructed in 1976. New bridges were constructed across the Rights River at Cloverville Road (R-3) in 1972 and across the West River at St. Andrews Street (McAmis Bridge) in 1976. A new bridge was also constructed across the South Rights River at Route 245 (R-4) in 1972. The locations of the above bridges are shown in Figure 5-1.

The frequent occurrence of flooding has resulted in a general awareness of the flooding problems in the study area. This awareness has led to the designation of flood hazard areas under the Town's Municipal Development Plan (Ref. 9). This plan was approved in May 1978 with the objective of controlling or restricting new development in areas susceptible to flooding. However, some development in the floodplain apparently continues to occur on lands under the jurisdiction of the County of Antigonish. The municipal boundary for the County and Town of Antigonish is shown in Figure 2-4.

2.6 Purpose and Scope of this Study

The basic purpose of this investigation was to provide the 1:20 and 1:100 year flood profiles for the following stream reaches in the study area:

1. The Rights River downstream of its confluence with the South Rights River.

2. The West River downstream of Highway 104.

3. Brierly Brook downstream of the flood control dam.

The scope of the study included the following investigations:

1. The collection and review of existing background information and reports.

2. The evaluation of the relative significance of various factors affecting flooding in the Antigonish area.

3. The development of a mathematical hydrologic model capable of determining design flows for Brierly Brook and Rights River. This includes the calibration and verification of the hydrologic models.

4. The development of a mathematical hydraulic model capable of simulating backwater profiles along the streams in the study area. This includes the calibration of the backwater model. The verification of this model was not possible due to the non-occurrence of high flow events.

5. The design and maintenance of a field program for the purpose of obtaining data for model calibration and validation.

6. Sensitivity analyses of the flood profiles in order to establish sensitive parameters and their relative significance in the backwater model.

7. Plotting of the 1:20 and 1:100 year recurrence interval flood lines on 1:2000 scale topographic maps

8. Identification of ice jam problems and the effect of ice jams on the open water flood profiles.

In addition, an attempt has been made to identify possible remedial measures which might be implemented to alleviate the potential flood damage problems.

The Terms of Reference for this study are presented in Appendix "b".

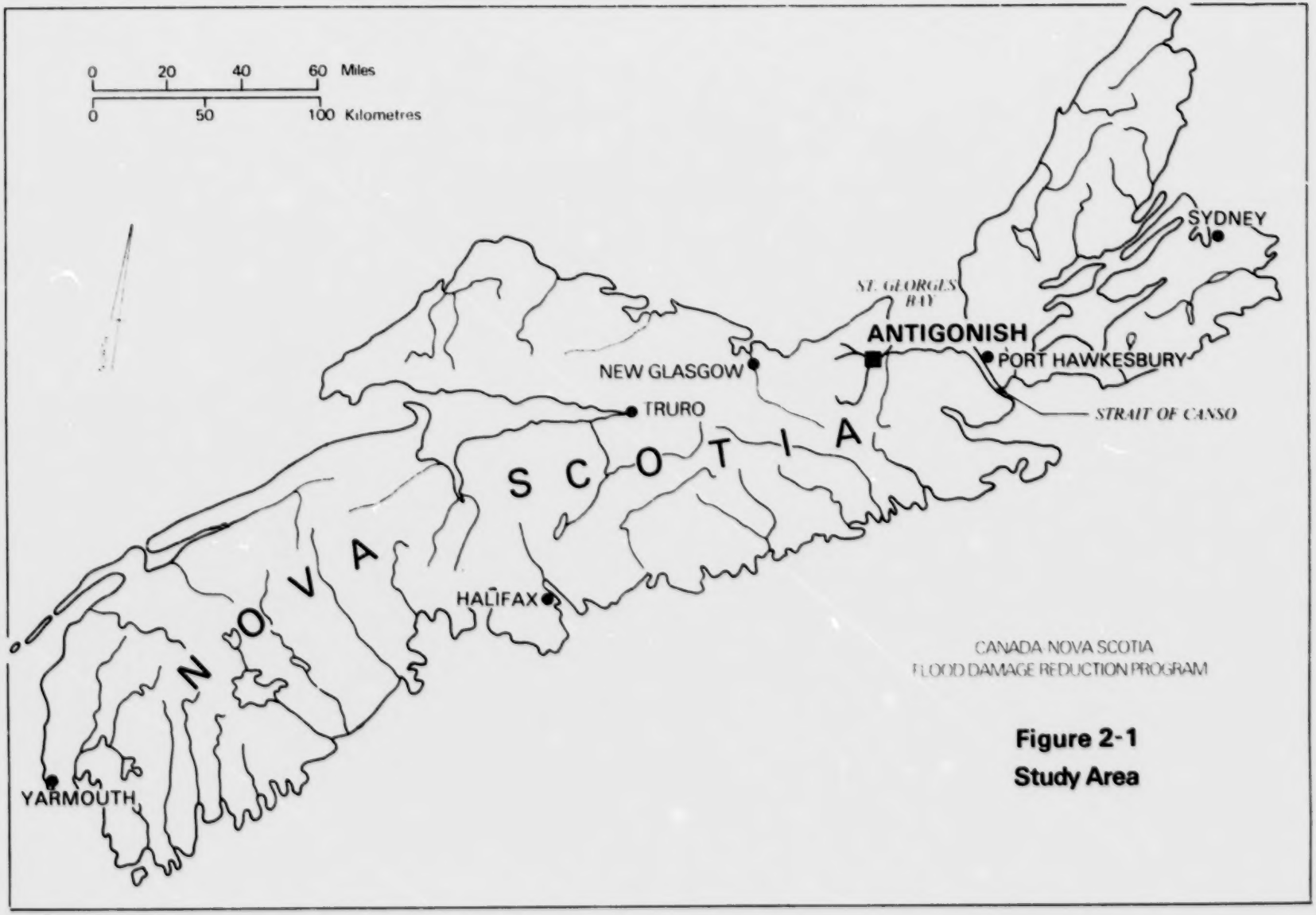
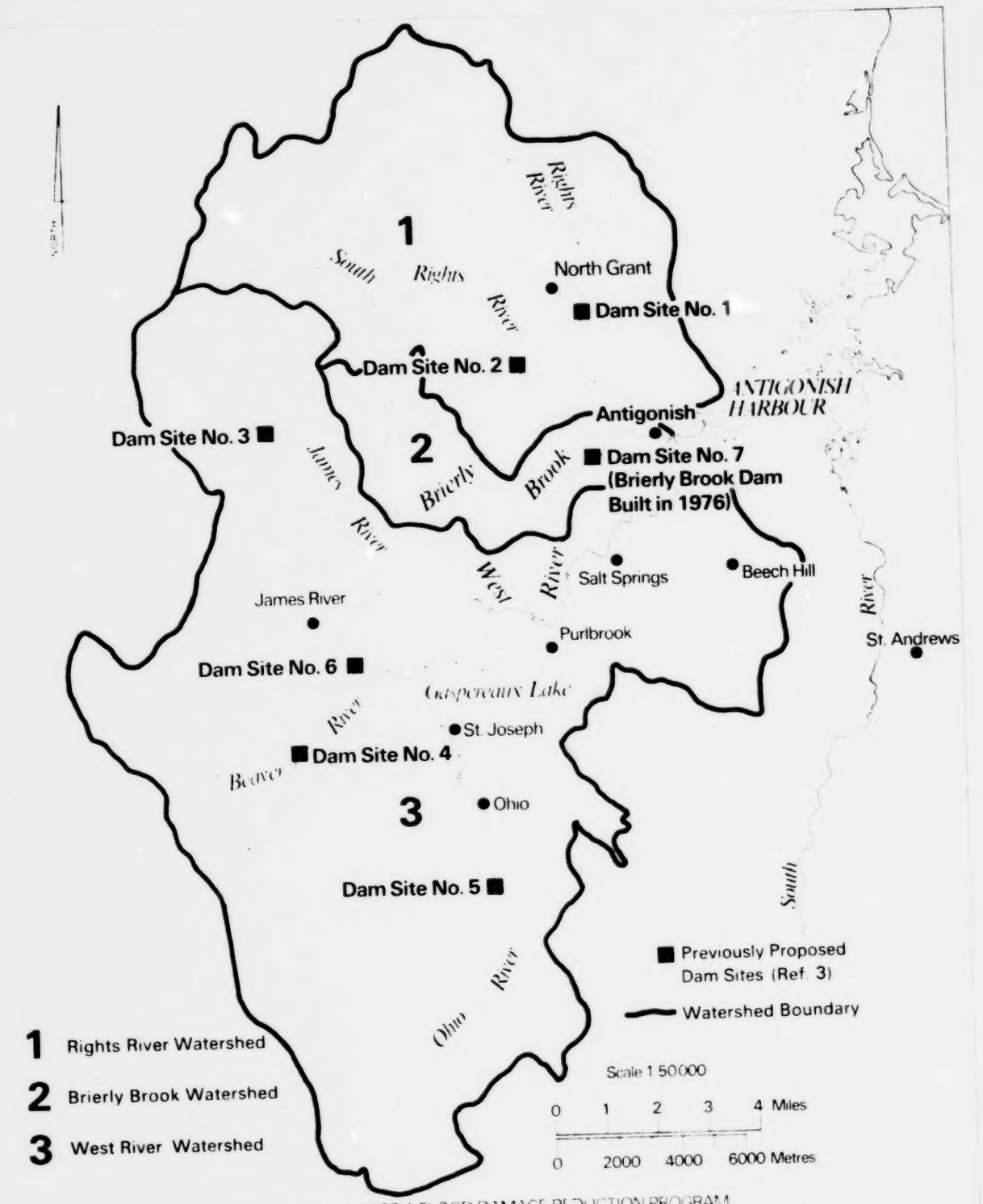


Figure 2-1
Study Area



CANADA NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure 2-2
Drainage Areas of
Rights and West Rivers and Brierly Brook

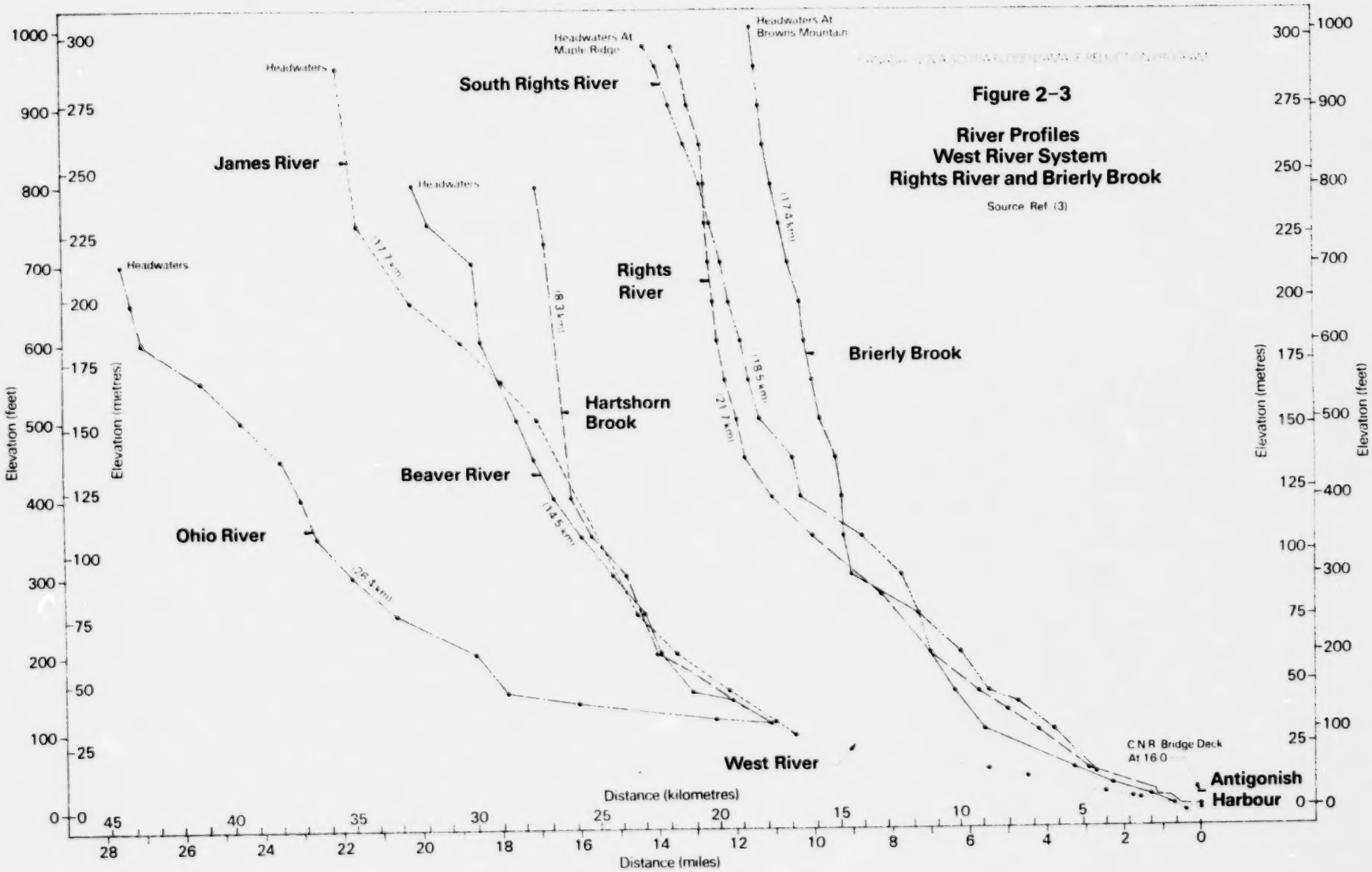


Figure 2–3
River Profiles
West River System
Rights River and Brierly Brook
Source Ref. (3)
Headwaters
James River
Headwaters
Headwaters At
Maple Ridge
South Rights River
Headwaters At
Browns Mountain
Rights
River
Brierly Brook
Hartshorn
Brook
Beaver River
Ohio River
West River
C N R Bridge Deck
At 16.0
Antigonish
Harbour
Elevation (feet)
Elevation (metres)
Distance (kilometres)
Distance (miles)

CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure 2-4
Flooding of the Antigonish Area by Hurricane Beth

Approximate Limit of Flood Plain

Approximate Built-up Area

Town Boundary

Metres 0 500 1000

Feet 0 1000 2000 3000 4000

NORTH

ROUTE 245

CLOVERVILLE ROAD

CANADIAN NATIONAL RAILWAY

South Rights River

HAWTHORNE STREET

ARBOUR DRIVE

BROOKLAND STREET

COLLEGE STREET

ANTIGONISH

MAIN STREET

ROUTE 337

Brook

Brierly

LAFERMORE AVE

DRIVE

ST. NINIAN STREET

HIGHLAND

WEST STREET

SAINT FRANCIS XAVIER UNIVERSITY

CHURCH STREET

ANTIGONISH MALL AREA

McAMIS BRIDGE

ROUTE 4

JAMES STREET

BRIERLY BROOK DAM

TRANS-CANADA HIGHWAY 104

West River

SOMERS ROAD

To Truro

To Sydney

CHAPTER 3 - PREVIOUS STUDIES

3.1 Hydrologic and Hydraulic Investigations

A recent Regional Flood Frequency Analysis (RFFA) (Ref. 14) provides estimates of the peak flows associated with floods for recurrence intervals of 1:20 and 1:100 years at the following locations:

1. Brierly Brook at the dam (without including the effects of regulation).

2. Mouth of Brierly Brook at West River (without including the effects of regulation).

3. Mouth of Rights River.

4. West River upstream of Brierly Brook.

5. West River downstream of Brierly Brook (without including the effects of regulation).

These data are tabulated and discussed in more detail in Section 6.0. Reference to the Regional Flood Frequency Analysis demonstrates the "flashy" nature of the Brierly Brook watershed, which exhibited a peaking factor of about 2.44 (ratio of instantaneous to maximum daily mean discharge). By comparison, the corresponding peaking factors estimated for the Rights and West River were 1.80 and 1.45 respectively.

In order to account for the small watershed and regulation effects of the Brierly Brook flood control dam, this investi-

gation (RFFA) (Ref. 14) recommended the use of a rainfall-runoff simulation technique for estimating peak flow hydrographs and routing these flood hydrographs through the flood control reservoir.

Other investigations have not included detailed analyses of peak flow estimates. However, a recent study by the Maritime Resource Management Service (MRMS) (Ref. 16) utilized hydrometric data measured on the South River to estimate peak flow rates on the West River near Antigonish Mall. The results of this analysis and Regional Flood Frequency Analysis (Ref. 14) results are summarized in Table 3. A comparison of the MRMS results with peak flow estimates derived from the Regional Flood Frequency Analysis indicates that the MRMS estimates of the mean daily discharges are in close agreement with the RFFA results whereas the estimated maximum instantaneous discharge transferred from the South River are somewhat higher than those derived in the RFFA.

Very few other investigations relating various peak flow rates and recurrence intervals were found in the background information. However, discharge estimates of peak flow rates which occurred on Brierly Brook were computed by the Maritime Resource Management Service (Ref. 19) based on water level measurements taken upstream and downstream of the College Street bridge during the occurrence of Hurricane Beth. These estimates indicated that the maximum flow rate at this location was close to 125 m^3/s (4400 cfs) during the occurrence of Hurricane Beth in 1971. This event was estimated in that study as having a 1:50 year recurrence interval for the study area.

TABLE 3

SUMMARY OF PEAK FLOWS ESTIMATED FOR
THE WEST RIVER NEAR ANTIGONISH MALL***

Recurrence Interval (year)	Estimated Mean Daily Discharge		Estimated Instantaneous Discharge	
	MRMS* m^3/s (cfs)	RFFA** m^3/s (cfs)	MRMS* m^3/s (cfs)	RFFA** m^3/s (cfs)
Annual	125 (4410)	N/A	155 (5480)	N/A
1:5	171 (6030)	N/A	259 (9130)	N/A
1:10	201 (7110)	N/A	338 (11930)	N/A
1:20	231 (8140)	208.3 (7357)	421 (14870)	306.9 (10840)
1:50	269 (9490)	N/A	540 (19070)	N/A
1:100	297 (10500)	285.2 (10073)	637 (22500)	420.4 (14850)

Source: Ref. 14 and 16

* MRMS - Maritime Resource Management Service (Ref. 16)

**RFFA - Regional Flood Frequency Analysis (Ref. 14)

N/A - Not Available

*** - Drainage Area: 391 km^2 (123 mi^2)

In 1972, peak flows were estimated by MRMS for the Brierly Brook watershed based on the runoff characteristics of the South River (Ref. 19). These estimates are summarized in Table 4. The peak instantaneous flows were assumed to be 2.4 times as large as the mean daily flows, which is consistent with the peaking factor determined by the Regional Flood Frequency Analysis. However, these flow estimates appear to be much lower than those referred to above for Hurricane Beth.

Some previous investigations (Ref. 16) have also determined that major rainstorms greater than 63.5 mm (2.5 inches) total volume in a 24-hour period generally result in some flooding of the study reach. The summary of heavy rainfall events given in Table 1 indicates that on this basis a number of flood producing events have occurred from 1918 to 1971.

Recent rainfall analyses were conducted as part of the Regional Flood Frequency Study (Ref. 14). Reference to this work will indicate that the 1:25 year 24 hour rainfall amount for the study area was approximately 120-132 mm (4.72 - 5.2 inches).

The current Truro Hydrotechnical Study (Ref. 20) includes an analysis of rainfall frequency and duration at Truro. Reference to the Regional Flood Frequency Analysis (Ref. 14) will indicate that, due to isohyetal patterns of peak rainstorm amounts in the province, the statistical analyses of rainfall intensity, frequency and duration at Truro can be considered to be applicable in the Antigonish area. The results of these analyses are summarized in Table 5.

TABLE 4

SUMMARY OF PEAK FLOWS ESTIMATED BY
MARITIME RESOURCE MANAGEMENT SERVICE
FOR BRIERLY BROOK AT THE CONFLUENCE WITH THE WEST RIVER
WITHOUT BRIERLY BROOK DAM

Recurrence Interval (Years)	Estimated Mean Daily Discharge		Estimated Maximum Instantaneous Discharge	
	m^3/s	cfs	m^3/s	cfs
1:27.5	16	565	42	1490
1:5.5	13	460	35	1240
1:2.75	12	425	32	1120
1:1.4	11	385	28	995

Source: Ref. 19

*Note: Peak flows estimates based on South River runoff characteristics

TABLE 5

RAINFALL FREQUENCY-DURATION ANALYSIS FOR TRURO

Return Period In Years	Duration — Rainfall Amounts (mm)								
	5 Min	10 Min	15 Min	30 Min	1 Hr	2 Hr	6 Hr	12 Hr	24 Hr
2	5.4	8.4	10.5	14.3	19.2	26.7	43.0	50.5	59.4
5	7.3	11.5	13.9	19.9	26.7	37.4	55.5	63.3	78.0
10	8.5	13.5	16.2	23.7	31.6	44.5	63.8	71.8	90.4
25	10.1	16.0	19.1	28.4	37.9	53.5	74.2	82.6	105.9
50	11.3	17.9	21.5	31.9	42.6	60.1	82.0	90.6	117.5
100	12.5	19.7	23.4	35.4	47.2	66.7	89.7	98.5	129.0

Source: Ref. 20

3.2 Engineering and Flood Control Measures

A number of investigations regarding engineering and flood control measures have been carried out for various locations within the study area. In 1966, a preliminary report (Ref. 2) was carried out to examine the feasibility of implementing flood and erosion control along the Rights and the West Rivers. This subsequently resulted in channel realignment and straightening (i.e. removal of meanders) in 1972 for the Rights River for a reach approximately 450 m (1480 ft.) in length starting approximately 450 m upstream of the Main St. Bridge (R-2). Proposals were also examined for straightening the West River at its confluence with Brierly Brook. This proposal has not yet been carried out.

In 1972, a report was prepared by Engineering Services, Department of Regional and Economic Expansion (Ref. 3) outlining a proposed flood alleviation program for Antigonish. The basic concept called for the construction of seven flood retardation dams to be built on the upstream tributaries in order to store stormwater runoff and to release it at a lower rate consistent with the capacity of the streams in the Town of Antigonish. The proposed level of protection of the engineering works was to control storms having a recurrence interval less than 1:50 years. Two reservoir sites were located on the Rights River, four sites were located on the West River and one site was located on Brierly Brook. The locations of these dam sites are shown in Figure 2-2. The proposed control system of dams was calculated to release an equivalent storage of 25 mm (1 inch) of runoff or .30 $m^3/s/km^2$ (27 cfs per square mile) into the river system while storing an additional 50 mm (2 inches) of runoff or 0.60

$m^3/s/km^2$ (54 cfs per square mile) so that a total runoff of 150 mm (3 inches) would be reduced to a discharge rate of .30 $m^3/s/km^2$. It was estimated that a flow of this size with some minor downstream channel improvements would not ordinarily overtop the river banks and therefore the proposed scheme would result in considerable flood control benefit. It was also determined that the proposed Brierly Brook structure could provide a higher capacity reservoir than the others, storing a 100 mm (4 inches) runoff rather than a 50 mm (2 inches) runoff. In 1972, the Maritime Resource Management Service (Ref. 18) refined the flood control proposals for Brierly Brook as an independent project. This structure was subsequently constructed in 1976, controlling 80% of the watershed drainage area and providing some degree of flood protection for the Town of Antigonish. According to the MRMS report (Ref.18) it was estimated that the flood control structure had the potential of maintaining discharges of about 65 mm (2.5 inches) or lower from the upstream watershed within the banks of the river within the town. However, when discharges in excess of 75 mm (3 inches) are produced from the above watershed, the influence of the dam would diminish and flooding of the Brierly Brook floodplain within the town would occur. Based on that study (Ref. 18), this was estimated to take place once in thirty years.

The stage/discharge and stage/storage curves for the Brierly Brook dam and reservoir are shown in Figure 3-1. The stage/discharge curve was derived based on dam outlet characteristics obtained from available dam drawings. Similarly, the stage/storage curve was determined from planimetering available topographic mapping of the dam site. The results shown in Figure 3-1 were compared with the curves derived by MRMS (Ref. 19) and found to be in close agreement.

In 1975, the Maritime Resource Management Service (Ref. 7) conducted a feasibility study for one of the dams previously recommended for the South Rights River. The proposed reservoir would be dual purpose for water supply and flood control and would control a drainage area of 39 km^2 (15 mi^2). This proposed flood control facility was estimated to be capable of reducing the more frequent flood peaks near the mouth of the river by about 20%, and was considered necessary to ensure a dependable water supply for the Town.

In 1975, a subsequent environmental and economic impact study was carried out for the South Rights River Dam (Ref. 17). That investigation considered this dam as dual purpose for flood control and low flow augmentation and discussed details of historical drought and flooding incidences. Flood damages associated with the 1971 flood event were estimated to be approximately $306,232 in the Antigonish area. It was pointed out that damage figures are not available for other flood events, but that most have not been as serious as this occurrence. However, it was assumed that within a given 10-year period, total flood damages amounting to between $400,000 and $500,000 could occur (1975 dollars). It was further estimated that the dam on the South Rights River could contribute to 16% of the total flood damage alleviation for the whole system. On this basis, the dam was attributed a flood control benefit of from $64,000 to $80,000 flood damage within a 10-year period (1975 dollars). It was concluded in general that the proposed structure on the South Rights River has no adverse environmental impacts and that if built should be a dual purpose facility which would control flood flows and provide low flow augmentation for water supply. In addition, it would alleviate water quality problems and provide

required flows for fire fighting. However, this dam has not been constructed as yet.

In 1978, a report was completed for the Town of Antigonish concerning the use of the James and South Rights Rivers as a water supply source for the Town of Antigonish (Ref. 10). Some preference was given to the James River as the new source of water supply since the watershed yield in low flow periods was somewhat higher than on the South Rights River. This analysis undertook population forecasts in the town and county based on a rate of increase of population of 1.5% per year over the next 50 years (1980 population forecast to increase to 11 400). A 1% student growth rate over the next 50 years was also assumed for attendance at the university (student population forecast to increase to 2600). In addition, the county was assumed to have a population of 2500 people served by the system, for a combined population of 16500 by the year 2030. As a result of this expected increase in population, the water consumption requirement were forecasted to increase from 5 (Mlpd) Million litres per day (1.1 Million Imperial Gallons per day (MIgpd)) to 8.18 Mlpd (1.8 MIgpd) in the year 2030.

In 1971, the Department of Highways commissioned a report (Ref. 4) concerning the McAmis bridge (W-2). Investigations revealed that the maximum channel capacity of the West River in the vicinity of the bridge was about 99.1 m^3/s (3500) cfs. It was recommended that a single span bridge be constructed in order to avoid ice jam problems at this location. It was noted that one of the factors which could contribute to potential ice jamming at the bridge was the turbulent flow caused by the short radius bend in the West River just upstream. Some consideration was therefore given to straight-

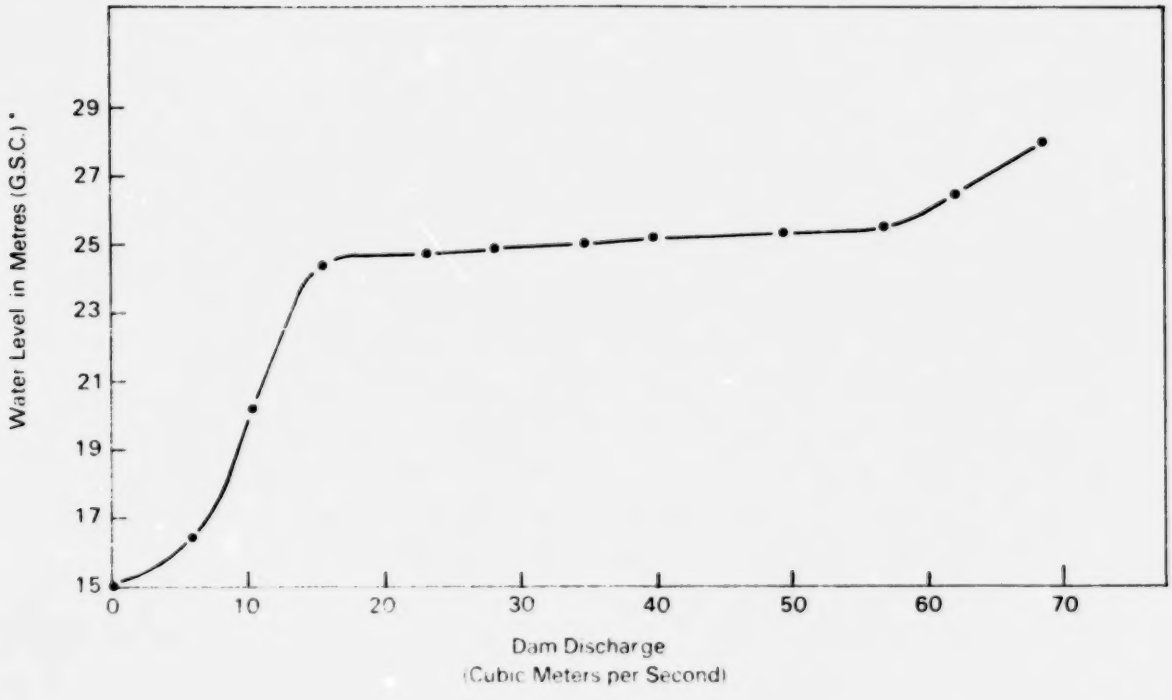
ening the channel, thereby reducing the potential for ice jams at this location.

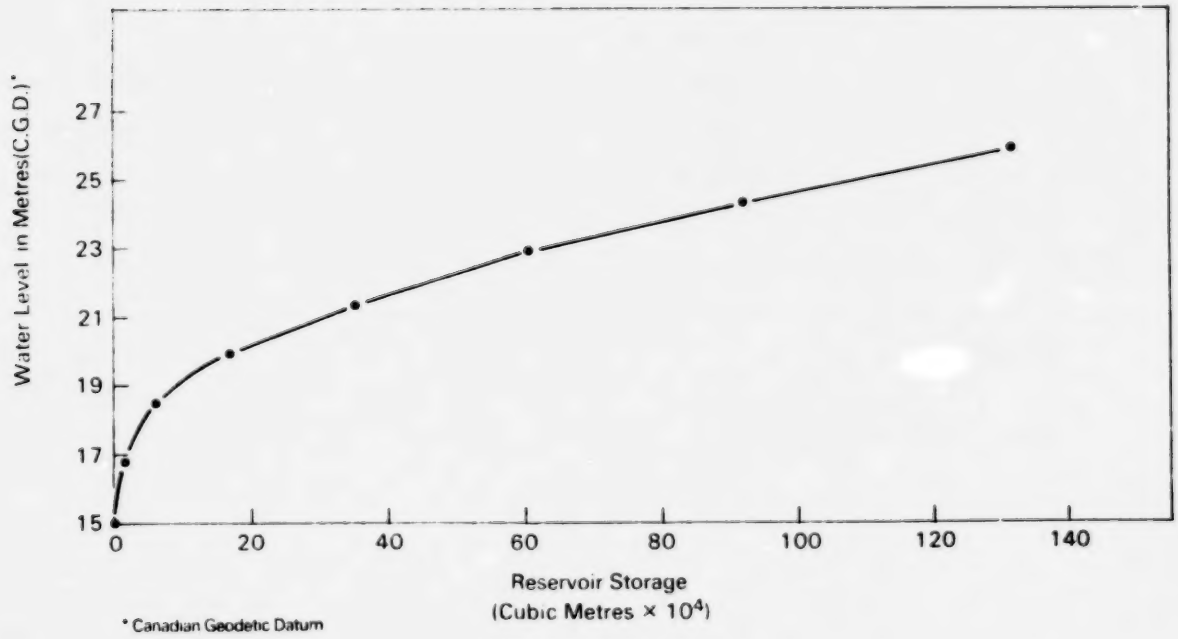
In 1978, an investigation was undertaken describing the environmental impacts of proposed floodplain infilling at a site of about 3.5 ha (8.7 acres) adjacent to Antigonish Mall (Ref. 8). This involved an analysis of the effects of placement of fill on lands which are now subject to occasional flooding and the assessment of the possible impact on aggravating flooding problems in the Town. The investigation noted the effectiveness of the Brierly Brook flood control dam in reducing peak flow events. An example cited was the high runoff event occurring January 14, 1978, resulting from a rainfall of 92 mm (3.63 inches) plus snowmelt. This event caused no flooding damage in the Town of Antigonish whereas flooding was experienced in other nearby locations.

It was also noted that the cause of most frequent flood damage within the Town of Antigonish is the damming effect at bridges within the Town, most notably at the Church Street bridge. This is exacerbated by the presence of ice resulting in ice jams and the low channel capacities in upstream areas. As a result of the preliminary analysis of the effects of fill in the floodplain adjacent to the Antigonish Mall, it was concluded that the placement of fill would result in an insignificant loss of floodplain storage and would not increase the vulnerability to inundation of areas within the Town of Antigonish. However, the effects on flow conveyance and upstream backwater levels were not discussed. A subsequent investigation in 1978 by the Maritime Resource Management Service (Ref. 16) recommended that the area to be filled should be modified in order to reduce encroachment into the floodway.

Stage / Discharge and Stage / Storage Curves for Brierly Brook Dam and Reservoir

Figure 3-1





* Canadian Geodetic Datum

CHAPTER 4 - AVAILABLE DATA

4.1 Hydrologic Data

Long term hydrometric measurements are not available for any location on the Rights River, West River or Brierly Brook watersheds. However, in October 1978, a continuous recording hydrometric station was installed on the Rights River at the upstream end of the study reach. This station is operated by Inland Waters Directorate, Environment Canada, with hydrometric data being published by their office in Halifax. Other nearby hydrometric stations and relevant data characteristics are summarized in Table 6. The locations of the hydrometric stations are shown on Figure 4-1. The Mean Annual discharge and Mean Maximum Daily discharge summarized in Table 6 for each of the hydrometric stations is derived from information found in the Historical Streamflow Summary (Ref. 23).

Temperature and precipitation data are collected by the Atmospheric Environment Service, Environment Canada, at a weather station recently established in Antigonish which has been operating since 1979. However, 25 years of precipitation data and 31 years of temperature data are available from a weather station which operated in Antigonish from 1882 to 1947 (not continuous). In addition, the Ashdale Meteorologic Station has operated since 1965, and also collects temperature and precipitation data. Another station was operated from 1916 to 1972 near the present Ashdale station known as Collegeville. The locations of these stations are shown in Figure 4-1 and a summary of available data is presented in Table 7.

TABLE 6

HYDROMETRIC DATA IN THE VICINITY OF STUDY AREA

Reference Number	Station WSC I.D.	Identification Name	Period of Record	Drainage Area km^2	Mean Annual Discharge m^3/s	Mean Annual Discharge $m^3/s/km^2$	Mean Maximum Daily Discharge* m^3/s	Mean Maximum Daily Discharge* $m^3/s/km^2$
1	01DR003	Rights River	1978-Date	64.2	2.35	0.037	21.2	0.33
2	01DR002	James River	1978-1979	52.1	N/A	N/A	N/A	N/A
3	01DR001	South River at St. Andrews	1917-1933 1965-date	177.0	5.63	0.032	66.47	0.38
4	01ER001	Clam Harbour River near Birchtown	1958-date	45.1	1.64	0.036	20.62	0.46
5	01E0003	E. River St. Marys at Newtown	1965-date	282.0	10.4	0.037	113.41	0.40
6	01DP004	Middle River at Rocklin	1965-date	92.2	2.79	0.030	27.34	0.30

N/A - not available

*Mean Maximum Daily Discharge is derived from information found in Historical Streamflow Summary

Source: Historical Streamflow Summary (to 1979) Atlantic Provinces (Ref. 23)

TABLE 7

ANTIGONISH AREA TEMPERATURE AND PRECIPITATION DATA

Antigonish Meteorological Station

(based on 31 Years Temperature and 25 Years Precipitation Data)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
Mean Temperature (°C)	-6.7	-7.8	-2.8	2.8	8.7	13.8	18.5	17.7	13.7	8.7	3.2	-3.2	5.6
Max. Temperature (°C)	19.4	15.0	20.6	27.8	32.2	35.6	37.2	37.8	34.4	26.7	24.4	18.3	
Min. Temperature (°C)	-35.6	-32.2	-31.1	-21.1	-11.1	-6.7	0.6	0	-5.6	-7.2	-17.8	-27.2	
Rainfall (mm)	48.5	39.7	47.2	58.2	93.0	71.6	77.2	77.9	95.0	111.0	105.4	54.9	930.7
Snow Depth (cm)	42.9	48.3	22.9	12.4	0.3	0	0	0	0	2.5	8.3	33.3	170.9
Total Precipitation (mm)	91.4	88.0	70.1	70.6	93.3	71.6	77.2	77.9	95.0	113.5	113.7	88.2	1050.5

Collegeville Meteorological Station

(1916-1972)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
Mean Temperature (°C)	-6.2	-6.9	-2.4	2.9	8.8	14.2	18.2	17.8	13.8	8.8	3.3	-1.4	5.8
Max. Temperature (°C)	15.6	15.0	22.2	27.7	33.9	35.0	36.1	38.3	34.4	28.3	25.6	16.7	
Min. Temperature (°C)	-34.4	-37.2	-30.6	-23.3	-7.2	-4.4	-1.1	-0.6	-6.7	-10.0	-18.9	-29.4	
Rainfall (mm)	68.1	55.1	61.0	68.8	83.1	82.6	77.6	104.9	89.9	111.3	120.7	83.3	1005.8
Snow Depth (cm)	45.5	43.4	34.5	14.5	1.3	0	0	0	0	1.5	10.2	45.0	195.8
Total Precipitation (mm)	113.6	98.5	95.5	83.3	84.4	82.6	77.6	104.9	89.9	112.8	130.9	128.3	1202.3

Source: Environment Canada, Atmospheric Environment Service

The stations identified above are manually operated so that rate of rainfall information is not available. The only station in the Antigonish area where rainfall intensities are available is at the Copper Lake Station. This station is located about 24 km (15 mi) south of Antigonish and operated from 1945 to 1974. From 1945 to 1970 it was operated as a manual gauge and from 1970 to 1974 as a recording gauge. Fortunately, this station was in operation when Hurricane Beth occurred in 1971 so that the rate of rainfall for this significant historical storm is available.

Other meteorologic data are also available from nearby stations maintained by the Atmospheric Environment Service. Active nearby stations include those located at Braeshore, Hopewell, Trenton, New Glasgow, Truro, etc. which are identified in Table 8 and shown in Figure 4-1. Active snowcourses in the area are identified in Table 9 and also shown in Figure 4-1.

Continuous tide levels are not measured at Antigonish Harbour, however, they are recorded at Pictou Harbour. The location of Pictou Harbour with respect to Antigonish Harbour is shown in Figure 4-1. Tidal observations for Pictou Harbour are available for the period 1965 to the present from Marine Environmental Data Service, Fisheries and Oceans Canada. Tidal predictions are also made for both Pictou and Antigonish Harbour and are available from Canadian Tide and Current Tables, Fisheries and Oceans Canada. In order to relate observed tide levels at Pictou Harbour to Antigonish Harbour, tidal observations were undertaken on 5 June 1981 at the CNR bridge (R-1) and the Main Street Bridge (R-2) on the Rights River. The tidal observations are further detailed in Section 5.8 of this report.

TABLE 8

CLIMATOLOGICAL STATIONS NEAR THE ANTIGONISH AREA

Reference Number	Station Name	Station Number	Type of Station	Period of of Record	Remarks
1	Antigonish	8200150	Manual	1882 - 1947 1979 - Date	Records not continuous
2	Collegeville (Ashdale)	8201000	Manual	1916 - 1972 1965 - Date	Station originally known as Collegeville and later relocated
3	Braeshore	8200590	Manual	1975 - Date	Precipitation only measured
4	Ecum Secum	8201700	Manual	1940 - Date	Continuous record
5	Hopewell	8202415	Manual	1968 - Date	Precipitation only measured
6	New Glasgow	8203900	Manual	1881 - 1896 1945 - Date	Record not continuous Record not continuous
7	Trafalgar	8205900	Manual	1919 - Date	Record not continuous
8	Truro	8205990	Recording	1870 - 1915	Continuous record from 1960
9	Upper Stewiacke	8206200	Manual	1915 - Date	Continuous record
10	Tipping Bucket* Rain gauge	N/A	Recording	1980-1982	Continuous record
11	Copper Lake	8201100	Manual Recording	1945-1970 1970-1974	Continuous record Contiuuous record

Source: Environment Canada, Atmospheric Environment Service.

* Gauge installed as part of field monitoring network for this study

TABLE 9

SNOW COURSES NEAR THE ANTIGONISH AREA

Reference Number	Location	Years of Record
1	Antigonish (Marshy Hope)	31
2	Sherbrooke (Stillwater)	26
3	Copper Lake (Goshen)	21
4	Musquodoboit	26
5	Truro (Masstown)	32
6	Middle River (Rocklin)	6
7	Purlbrook	6

Source: Environment Canada, Atmospheric Environment Service.

The mean monthly higher high water levels computed from observed water levels at Pictou Harbour from 1965-1979 are presented in Table 10.

As pointed out in Section 3.1, rainfall distributions for Truro are considered to be applicable to the Antigonish area. One hour and 12-hour rainstorm characteristics are summarized in Figures 4-2 and 4-3 for Truro (source: Atmospheric Environment Service). The rainfall-intensity-duration curves for Truro are also summarized in Figure 4-4.

One of the largest floods on record in the study reach was associated with the occurrence of Hurricane Beth in 1971. Inland Waters Directorate (Ref. 11) has undertaken a preliminary analysis of the flood following Hurricane Beth at various locations in Nova Scotia. Table 11 indicates the temporal and geographic distribution of the rainfall amounts resulting from this event. From Table 11, it is evident that this event was centred near in the Antigonish area. In general, it was found that the time distribution of this rainfall event caused high runoff resulting in record setting floods in most of eastern Nova Scotia.

4.2 Hydraulic Data

Channel characteristics and the temporal variation can be derived from existing aerial photography and topographic mapping available for the study reach. The following aerial photography is available for the Antigonish area:

TABLE 10

MEAN MONTHLY HIGHER HIGH WATER LEVELS OBSERVED AT PICTOU HARBOUR*

Month	Mean Monthly Higher High Water Level (metres - G.S.C.)
January	0.94
February	0.86
March	0.82
April	0.79
May	0.74
June	0.75
July	0.77
August	0.79
September	0.79
October	0.83
November	0.86
December	0.94

* Based on 1965-1979 period of record.

Source: Marine Environmental Data Service, Fisheries and Oceans Canada, Ottawa.

TABLE II

HURRICANE BETH

PRECIPITATION FOR 6 HOUR INTERVALS (mm)

	AUG 15				AUG 16				AUG 17			
Station	06Z	12Z	18Z	00Z	06Z	12Z	18Z	00Z	06Z	12Z	18Z	TOTAL
Yarmouth		21.8	16.3	36.8	[illegible]	[illegible]						75.9
Western Head	1.0	31.0	45.7	38.7	52..	6.1	T	T				179.8
Greenwood		22.1	11.2	28.9	[illegible]	[illegible]	20.6	7.1				101.1
Shearwater		49.6	32.2	80.5	21.8	12.5	2.0	20.1	0.76			240.3
Halifax Airport		56.6	29.7	81.3	[illegible]	[illegible]	6.8	21.8	1.3			296.4
Truro		31.8	24.9	28.4	15.7	2..6	2.2	2.8	0.5			131.1
Canso			6.1	3.3	1.0		4.8	T	5.8	0.76		21.8
Sydney		0.30	9.8	40.4	6.9	0.25	6.6	3.6	2.3	0.25		69.9
Charlottetown		T	3.8	5.1	22.8	12.7	20.6	8.6	T			73.4
Summerside			1.5	1.0	9.1	13.5	27.2	0.25				52.6
Moncton			0.25	8.3	14.9	10.4	13.7	1.3				49.0
Saint John				3.8	[illegible]	T	6.4	[illegible]				19.6
Copper Lake		28.0	57.7	70.4	[illegible]	14.9	[illegible]	4.9	5.1			261.0

NOTE: Z = Co-ordinated Universal Time
T = TRACE (0.01")

Date	Scale
1964	1:15 840
1969	1:15 840
1970	1:40 000
1971	1: 6 000
1974	1:10 000
1980	1: 8 000

Topographic mapping at a scale of 1:1200 was produced from the 1971 aerial photography flown at a scale of 1 inch to 500 feet and is available from the Nova Scotia Department of Lands and Forests. Orthophoto mapping at a scale of 1:10,000 with 5 metre contour intervals is also available from the same source. As part of the present study new topographic mapping at a scale of 1:2000 has been produced for the study reach from the 1980 photography.

The major purpose of this study is to provide detailed flood-line mapping for the study area. However, water levels measured in the field after the occurrence of Hurricane Beth are presently used to delineate flood hazard areas in the Town of Antigonish as described in the Municipal Development Plan (Ref. 9)(see Figure 2-4). Water surface elevations along various points in the study reaches resulting from the Hurricane Beth flood event are presented in Table 12 (Ref. 8). Hurricane Beth flood profiles for Brierly Brook and West and Rights Rivers are shown in Figures 7-2, 7-3 and 7-4.

General information on streambed profiles for Brierly Brook and the Rights and West Rivers is available from topographic mapping (see Figure 2-3) and previous engineering studies.

TABLE 12

OBSERVED HURRICANE BETH PEAK WATER SURFACE ELEVATIONS WITHIN STUDY AREA

Watercourse	Location*	Observed Peak Water Surface Elevation	
		m	(feet)
Brierly Brook	East Side of College Street, between College and Church Streets	4.51	(14.8)
Brierly Brook	Downstream of Main Street Bridge	6.74	(22.1)
Brierly Brook	Upstream of Main Street Bridge	7.83	(25.7)
Brierly Brook	Adjacent to Antigonish Regional High School	11.06	(36.3)
West River	East of McAmis Bridge (St. Andrews St.)	3.29	(10.8)
West River	West of McAmis Bridge	4.42	(14.5)
Rights River	Harbour Side of CNR Railroad Trestle	2.44	(8.0)
Rights River	Downstream of Main Street Bridge	4.24	(13.9)
Rights River	Upstream of Main Street Bridge	4.54	(14.9)
Rights River	400 feet Upstream of Old Cloverville Road Bridge	7.41	(24.3)

*Refer to Figure 2-4 for extent of area flooded

Source: Ref. (8)

In addition, cross-section data were measured at various locations along Brierly Brook in conjunction with preliminary engineering studies carried out for the flood control reservoir.

4.3 Ice Conditions

Systematic observations of ice thickness and the dates of freeze-up and break-up are not available at Antigonish, but have been observed on rivers and lakes in the region since the winter of 1940-41 (Ref. 10).

These observations suggest that rivers in the study area are usually ice covered by late December and attain a mean maximum thickness of about 41 cm (16.1 m) by mid-winter. During the winters of 1981 and 1982, ice thicknesses on Brierly Brook and Rights River ranged between 30 cm and 38 cm (12 and 15 in); well within the long-term observed range of 5 cm to 91 cm (2 to 36 in).

Mid-March marks the usual beginning of break-up on small streams and rivers in the area and these tributaries are generally clear of ice by the end of March. Harbours and large rivers, such as the West River, are usually free of ice by mid-April.

It was noted in Table 2, however, that the combination of warm weather and rainfall occasionally modifies this general process and contributes to premature break-up and the development of ice jams in winter months. The lower reach of Brierly Brook has been affected most frequently by these conditions, and premature ice break-up have resulted in flooding on at least seven occasions in the last 30 years.

Although it appears likely that ice jams on the Rights River contributed to flooding in 1935 and 1956, it was not until 1982 that an ice jam of significance was observed and monitored. There is very little information on ice conditions and break-up on the West River. Accounts of break-up on Brierly Brook allude to ice cover on the West River remaining consolidated for longer than that on Brierly Brook and inhibiting the discharge of ice from the brook and contributing to flooding. Break-up on the West River itself is reported to have caused flooding in 1956 and 1971 as a result of ice jams at the piers of McAmis Bridge (a new bridge without piers has been installed since then, however).

In general, data on ice conditions in Antigonish are scattered and mostly qualitative in nature prior to 1981 and 1982. Although most likely the days in which ice related flooding has occurred in the area have been recorded since the turn of the century, practically nothing else is known about the ice conditions or for certain which rivers experience ice problems.

Northumberland
Strait
Amet
Sound
River John
Pictou
Pictou
Harbour
3
6
New Glasgow
6
6
Middle River
5
1
Cobequid
Bay
Truro
8
5
9
7
4
Ecum
Secum
4
Atla

CANADA-NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure 4-1
Relevant Monitoring Network

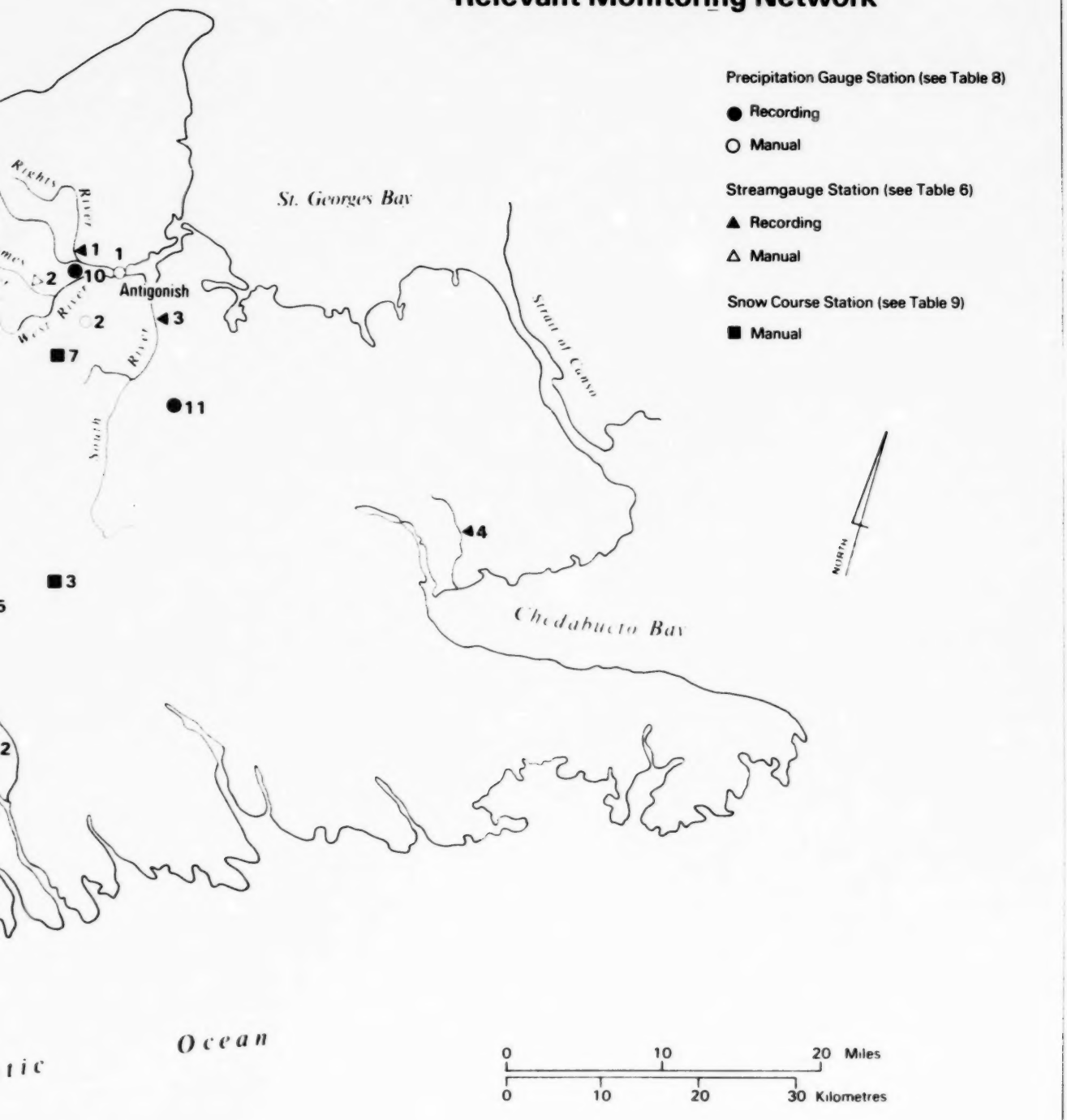


Figure 4-2
1 Hour Storm Rain Distribution
Truro Nova Scotia

No. of Events = 18

Selection Criteria (mm • 10)	5 Min.	1 Hr.
	63	178

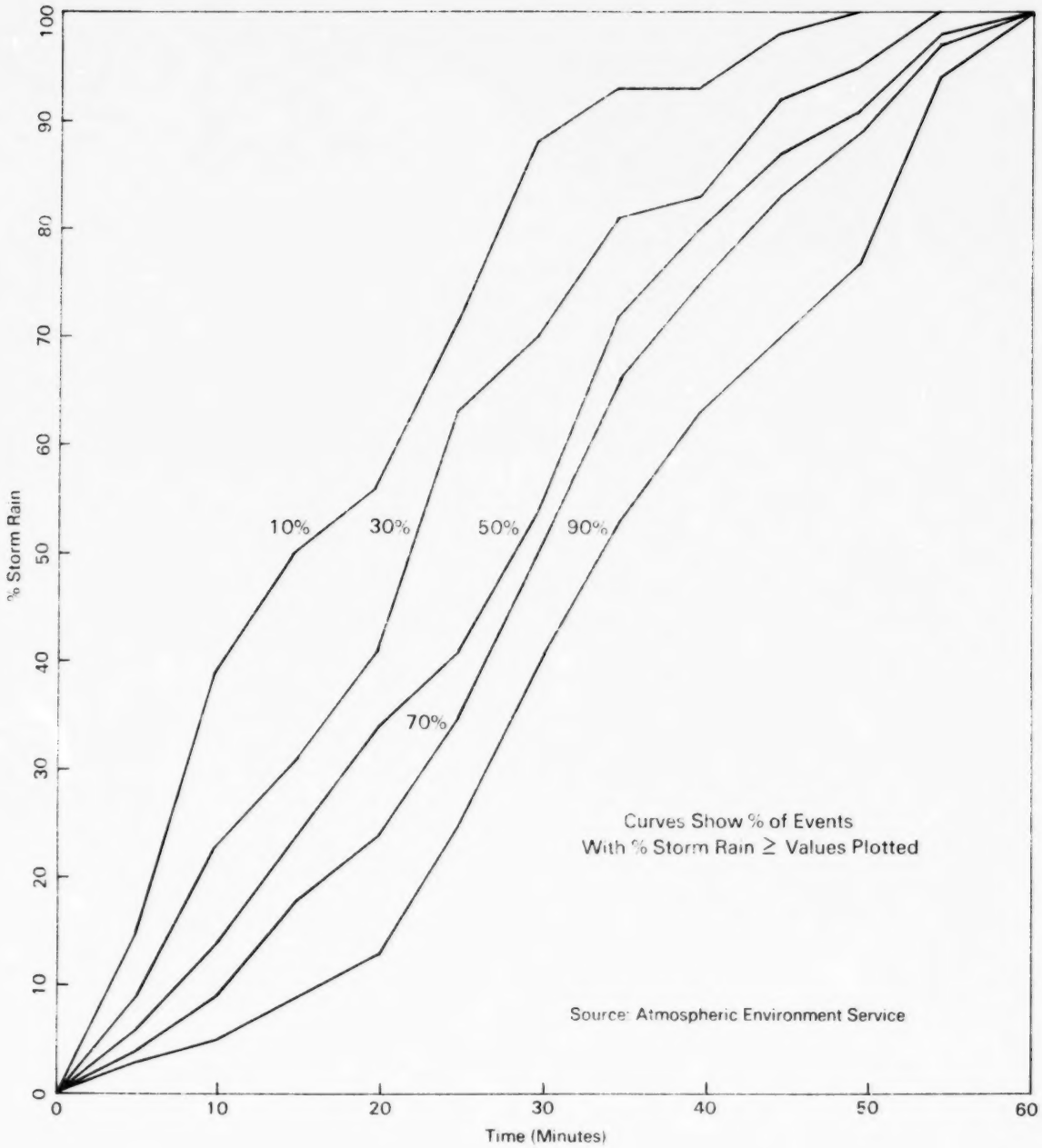
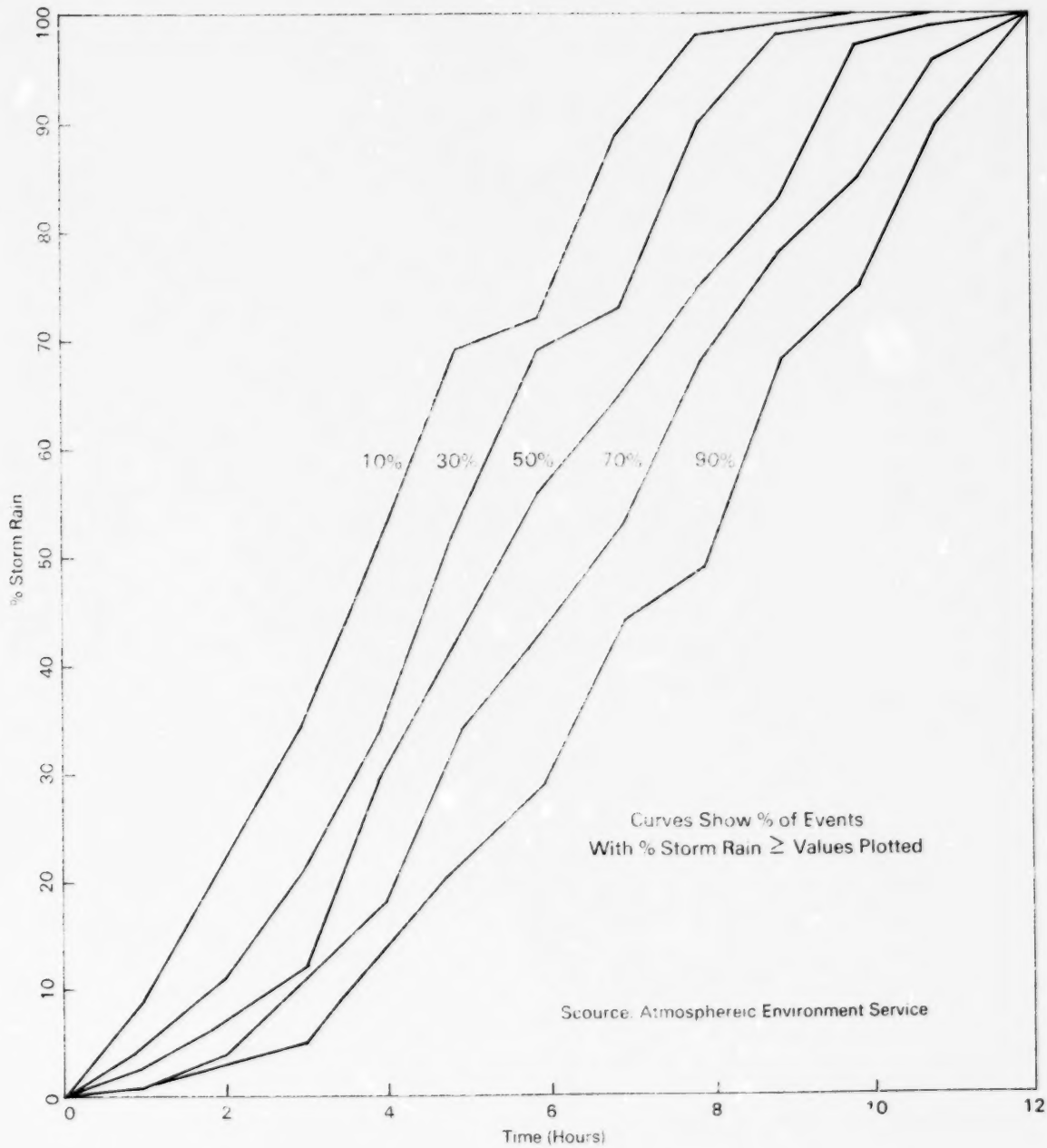


Figure 4-3
12 Hour Storm Rain Distribution
Truro Nova Scotia

No. of Events = 23

Selection Criteria :	6 Hr.	12 Hr.
(mm • 10)	••	470



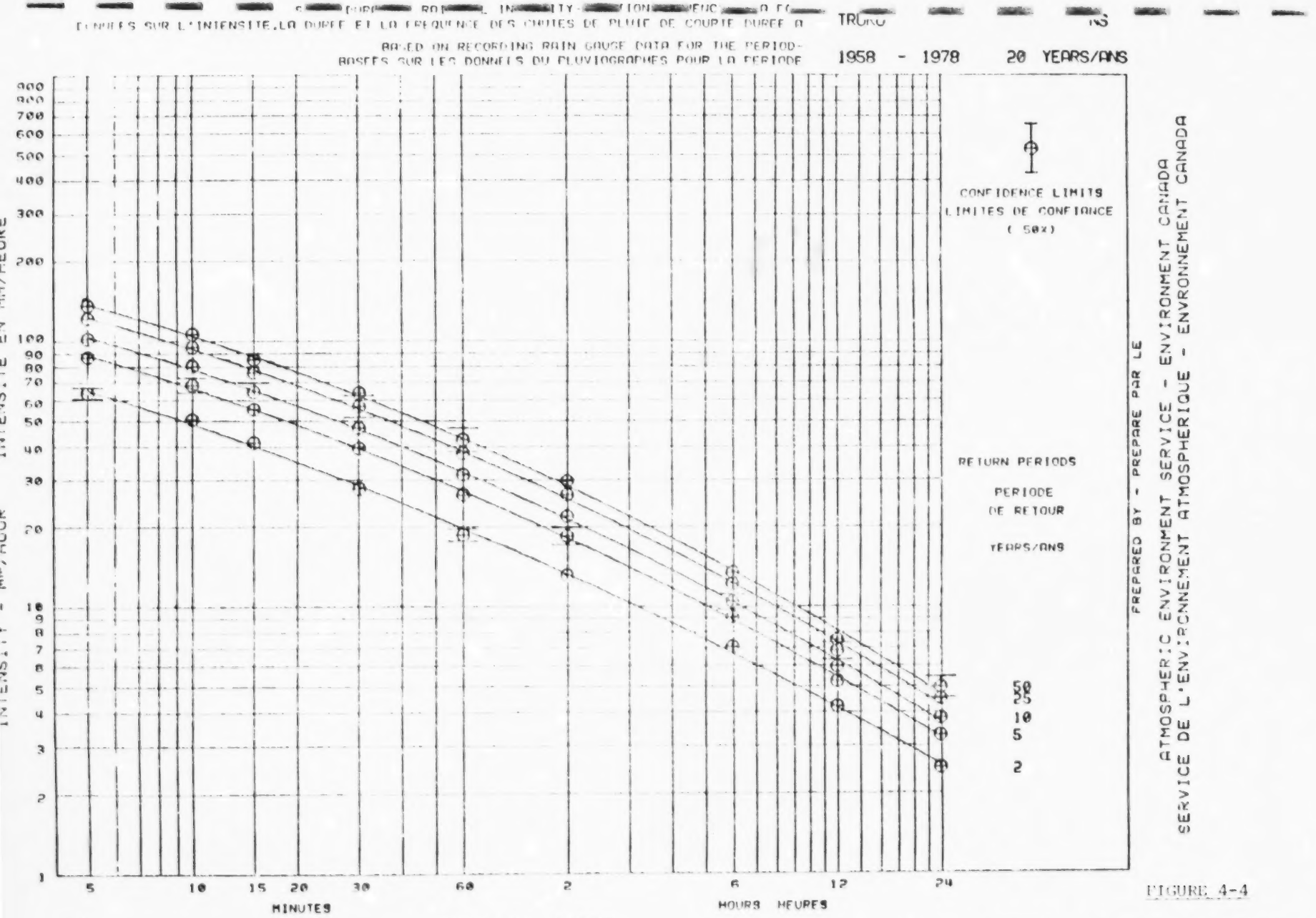


FIGURE 4-4

RAINFALL-INTENSITY-DURATION CURVE FOR TRURO, NOVA SCOTIA

CHAPTER 5 - FIELD SURVEY PROGRAM

5.1 General

A data collection program was designed and undertaken to collect information suitable for model calibration/verification. Equipment which was installed in the field was comprised of staff gauges, crest gauges, and a tipping bucket rain gauge to monitor water levels and precipitation amounts. Additional field surveys were undertaken to collect physical data consisting of channel and floodplain cross-sections and measurement of hydraulic structures within the study reaches. Photographs were also taken to aid in the estimation of roughness coefficients. The field monitoring program was started in November 1980 and ended in May 1982.

5.2 River Cross-sections

The study limits for this study are as follows: Rights River from the CNR trestle near Antigonish Harbour to the confluence with the South Rights River; West River from the CNR trestle to upstream from Trans-Canada Bridge (104) and Brierly Brook from its confluence with the West River to the Brierly Brook Dam. Approximately 127 river cross-sections were used to develop a mathematical model to represent the hydraulic characteristics of the channels and floodplains within the study area. Initially, the sections were derived from 1:2000 topographic mapping having a contour interval of 1 metre. To field check the mapping and to verify the procedure for obtaining data from the mapping, field surveys were undertaken to collect a representative sample of these sections. Approximately 25 representative cross-sections were surveyed. The locations of these sections are shown in Figure 7-1.

Field surveys were undertaken by a three-man survey crew using a Wild automatic level. G.S.C. monuments for the Antigonish area were obtained from the Nova Scotia Department of Lands Forests and the Department of Energy, Mines and Resources, Canada. These monuments were then used by the field survey crew to establish benchmarks at suitable locations within the study area. Survey loops were closed to ensure acceptable standards were being met. Overbank cross-sections were obtained by measuring the elevations with the level and distances with a steel tape. Measurements were taken where there was a significant change in topography. In- channel bottom elevations were obtained by sounding from bridges or walking across the channel where possible.

Sections selected for field survey were chosen on the basis of ease of access, proximity to benchmark references, and the requirement of obtaining a representative check of cross-sections throughout the study area. Each section was surveyed at least within the high water lines of Hurricane Beth and beyond these limits in many cases. The orientation of the sections was established in the field by reference to nearby landmarks such as buildings or transmission poles which were evident on the topographic mapping. The cross-sections used as input to the hydraulic model and the extent of surveyed cross-sections are shown in Figure 7-1. Representative cross-sections of each stream are shown in Appendix "C".

The elevations surveyed were referenced to either a G.S.C. benchmark or to the gauge reference points as described in Section 5.4. and presented in Table 13. In all cases a close correlation was found between topographic map data and data obtained from the field.

TABLE 13

GAUGE LOCATIONS

River	Gauge Location Reference	Type of Gauge	Bridge Name At Crossing	Reference Elevation GSC (m)	Gauge Location**
Brierly Brook	B-1	SG	Church Street	5.552	Corner of concrete wing wall
	B-2	SG, CR	College Street	8.954	Corner of concrete sidewalk
	B-3	SG	Main Street	7.546	Corner of bearing wall
	B-4*	SG, CR	Braemore Avenue	9.710	Corner of bearing wall
	B-6*	SG	Somers Road	N.A.	Referenced to bolt (not tied to GSC)
Rights River	R-1	SG, CR	Canadian National Railway	4.963	Top of CNR Rail
	R-2	SG	Main Street	4.152	Corner of bearing wall
	R-4*	SG	Cloverville Road	8.764	Corner of concrete sidewalk
	R-4	SG	Route 245	17.145	Concrete nail in bridge pier
West River	W-1	SG	Canadian National Railway	4.946	Top of CNR Rail
	W-2	SG	St. Andrews Street	3.604	Corner of concrete bearing wall
	W-3*	SG	Trans Canada Highway (Route 104)	3.878	Steel form tie protruding from concrete wall

* Flow metering was also carried out at these sites.

** GSC Monuments at each gauge are identified in the bridge drawings presented in Appendix "A".

Legend: B - Brierly Brook
R - Rights River
W - West River
SG - Staff Gauge
CR - Crest Gauge

5.3 Structures

At the outset of the study, construction drawings were obtained from Nova Scotia Department of Transportation (NSDT) and Canadian National Railways (CNR) for bridges spanning the watercourses in the study area. For the drawings obtained, visual checks were conducted in the field to ensure that the structures were built to plan. In some cases, drawings could not be obtained and consequently a field survey was conducted to determine the physical properties of these structures. A summary of the information obtained from these sources is presented in Table 14. Elevation and plan views of the structures are shown in Appendix "a".

5.4 Discharge and Water Level Measurements

For the purpose of relating water levels to Geodetic Survey of Canada (G.S.C.) data, a total of twelve staff gauges were installed at strategic locations. To record unobserved peak water levels, three crest gauges were also installed. Each gauge was located adjacent to a stream crossing for ease of access and to provide a rigid support for the equipment. For reference purposes, each gauge location has been assigned an alpha-numeric reference as shown in Table 13. A map showing the location of the equipment installed in the study area appears in Figure 5-1.

Plastic levelling rod facing or metal facings were affixed to 50 x 150 mm lumber to fabricate the staff gauges. Each gauge was then securely fastened to the bridge's understructure or retaining walls by means of concrete nails.

TABLE 14

BRIDGE CHARACTERISTICS

Bridge	Low Chord Elevation (m)	Top of Road Elevation (m)	Net Bridge Opening (m)	Min. Distance Below Low Chord (m)	Max. Distance Below Low Chord (m)	Area of Bridge Opening (m^2)
B-1	4.9	5.4	14.6	1.5	2.5	29.2
B-2	7.9	9.1	13.7	4.0	4.4	59.0
B-3	7.8 (avg)	9.2 (avg)	15.1	2.7	3.4	47.5
B-4	10.0	11.1	12.0	2.6	2.8	32.4
B-5	N.A.	N.A.	7.2	N.A.	4.1	23.5
R-1	3.7	6.3	25.8	2.2	4.8	95.3
R-2	4.9	5.8	36.1	2.4	4.2	124.9
R-3	7.4	9.0	30.6	3.3	3.8	115.7
R-4*	N.A.	N.A.	50.0	0.5	5.5	129.7
W-1	3.6	4.9	50.9	3.0	4.9	174.7
W-2	6.6 (max)	4.0 (max)	40.6	0.9	5.5	173.3
W-3	7.1	8.3	33.4	4.7	5.4	171.0
Trestle (including W-1 and R-1)	3.6	4.9	271.5	2.4	4.9	676.6

* Due to the height and width of this bridge, the values shown are for a flow channel extending to the CNR track.

The crest gauges were located on Brierly Brook at College Street (B-2), Braemore Avenue (B-4), and at the CNR bridge (R-1). The gauges were fabricated from casing of 100 mm Ø ABS pipe and contained inside with a 37 mm Ø ABS indicator pipe. Grated styrofoam was used to record water levels for the crest gauges.

Each gauge was referenced to a nearby non-moveable reference point so that it could readily be re-referenced if dislodged. Each reference point, with the exception of the Somers Road Bridge gauge (B-6), was referenced to G.S.C. datum. The locations of the gauges and reference points in relation to the structures to which they were fastened are shown in Appendix "a".

Staff gauges were not installed at Brierly Brook Dam, but reference elevation marks at 1 metre (3.3 feet) intervals were marked on objects on the upstream side of the dam so that the stage at the dam could quickly be determined during runoff events. The reference point used for these marks was the top of the concrete at the upstream low flow outlet culvert, elevation 16.76 m (54.9 feet) as determined from construction drawings.

Gauging station B-6 at Somers Road is located outside the study area but was gauged because of the importance of determining the inflow to Brierly Brook Dam. Field surveys were carried out to establish the slope of the corrugated steel pipe arch culvert under Somers Road to compute the theoretical discharge through the culvert as a means of comparison with the metered flow. With the slope, the length of the culvert and the difference in head and tail water levels all

known, the theoretical flow at this location could be readily determined and compared to the observed flow (metered).

During periods of impending high water levels, staff gauge readings were taken at all locations to record the river levels. In the event that monitoring did not coincide with peak flows, the crest gauges were used to ascertain peak water levels.

Four temporary hydrometric stations were established to measure river flows at the following bridge gauging locations: Braemore Ave. (B-4), Somers Road (B-6), Cloverville Road (R-3) and Trans-Canada Highway 104 (W-3). The hydrometric stations were selected at key locations within the study area to obtain flows to calibrate/validate the hydrologic and hydraulic models. Prior to the final selection of metering locations, the sites were visited with personnel from the Water Resources Branch of the Inland Water Directorate, Environment Canada. Metering procedures were reviewed at that time and the peculiarities of each site were discussed. The metering stations at each of the locations identified above (B-4, B-6, R-3, W-3) are shown in Appendix "a".

Removable markers were attached to the bridge handrail at B-4, R-3 and W-3 to note the location of the metering panels. At B-6, a wooden frame capable of supporting the metering weight and reel was constructed and the panel locations were scribed on this frame.

Flow metering at each location was undertaken when water levels exceeded pre-determined levels.

Flow metering was conducted using a Price 622 AA current meter in conjunction with a 22.7 kg lead weight. The meter was calibrated at the Canada Centre for Inland Waters prior to use.

Typical gauge installations are shown in Appendix "d".

5.5 Precipitation Data

As part of the field instrumentation, a recording rain gauge was installed within the upper reaches of the study area as shown in Figure 5-1. The rain gauge installed is a model 2501 tipping bucket rain gauge with a Type B MSC recorder. The gauge was located on the property of Dr. R. Lienime near Somers road and Brierly Brook. It was installed in an open area in accordance with procedures recommended by the Atmospheric Environment Service. The recorder which uses weekly recording charts was located in the basement of Dr. Lienime's house. The recorded weekly charts were forwarded to A.E.S. for reduction. Rainfall intensity data for the station were determined only when fairly high peaks were observed within the study area.

5.6 Rainfall-Runoff Data

As indicated previously, the duration of the field monitoring program was from November 1980 to May 1982. During this period, there were few events which produced high peak flows. High flows were observed within the study reaches during the 1982 spring break-up but unfortunately the high flows were accompanied by ice floes and consequently metering was not possible. An intense storm did occur in the Antigonish area

between 10:45 PM on 20 November and 2:15 PM on 21 November 1981. During this period, 70.3 mm (2.77 inches) of rain were recorded at the recording tipping bucket raingauge installed near Somers Road in the Brierly Brook watershed, as indicated in Figure 5-1. The rainfall seems to have been highly variable as 36.8 mm (1.45 inches) were recorded at the Collegeville station (8201000) and 52.0 mm (2.05 inches) at the Antigonish station (8200150).

This November storm was preceded by heavy rain in the previous three weeks which resulted in wet soil moisture conditions and consequently led to a high volume of runoff. Unfortunately, due to the quick response of the Brierly Brook watershed and the difficulty in metering during adverse weather conditions, it was not possible to obtain complete flow hydrographs at any location to estimate the peak flows. Flows were to be monitored at the locations indicated in Figure 5-1 but because of the problems encountered, it was possible to take only some spot measurements, when the water levels were receding. The metered flows at each of these locations are shown in Table 15. The peak flow observed at the recording streamgauge on the Rights River near Antigonish (see Figure 6-1) was 84.3 m^3/s (2977 cfs).

Spot water level readings were also taken at the Brierly Brook reservoir. It was also possible to obtain the peak water level at the reservoir since the high water created grass markings which were later surveyed. Based on the stage-discharge curve shown in Figure 3-1, the calculated discharge from the dam was determined. These results are also presented in Table 15.

TABLE 15

OBSERVED FLOWS AND PEAK WATER LEVELS DURING THE 20/21 NOVEMBER 1981 STORM EVENT

Location	Date	Approximate Time	Metered Flow m^3/c (cfs)	Observed Peak Water Surface Elevations m	(feet)
Brierly Brook at Somers Road Bridge (B-6)	21 Nov.	18:30	9.0 (318)	Not Available	
Brierly Brook Braemore Ave. Bridge (B-4)	21 Nov.	17:30	13.8 (487)	8.30	(27.23)
Rights River at Cloverville Road Bridge (R-3)	21 Nov.	21:00	38.8 (1370)	5.62	(18.44)
West River at Highway 104 Bridge (W-3)	21 Nov.	23:00	82.6 (2917)	4.23	(13.88)
Brierly Brook Dam (from stage-discharge curve)	21 Nov. 21 Nov. 22 Nov.	14:50 19:25 1:12	8.5 (300) 10.8 (382) 9.3 (329)	17.83 19.14 18.63	(58.5) (62.81) (61.12)
Brierly Brook at College St. Bridge (B-2)	21 Nov.	18:00	Not Measured	5.01	(16.4)
Rights River at CNR Bridge (R-1)	21 Nov.	21:30	Not Measured	2.0	(6.6)

During the course of the field monitoring, two other storms occurred in the Antigonish area which produced heavy rains. One occurred on 22-23 May 1981 and produced 83.1 mm (3.27 inches) in a 30-hour period. The other occurred on 13-14 May 1982 and produced 45.5 mm (1.79 inches) in a similar time span. The rainfall amounts recorded at the Collegeville and Antigonish Climatological Stations seem to indicate that the rain was fairly uniformly distributed over the study area watersheds for both events.

The runoff generated by these storms was not very high and consequently the flows were not measured. The peak flow recorded at the Rights River hydrometric station was 25 m^3/s (883 cfs) for the May 1981 storm event and 30.7 m^3/s (1085 cfs) for the May 1982 event.

The rainfall hyetographs and the simulated flow hydrographs for the storms described above are shown in Figures 6-2 to 6-5 for Brierly Brook and the Rights River.

Water levels were also measured and recorded during the various storm events identified above. Since the November 1981 storm event produced the highest water levels during the field monitoring program, they were used to calibrate the hydraulic models for each of the study reaches. Peak water levels observed for this storm are presented in Table 15 and are also shown as water surface profiles in Figures 7-2 to 7-4 for Brierly Brook and the Rights and West Rivers.

5.7 Break-up Ice Observations

Ice conditions were noted during break-up in the winters of 1980-81 and 1981-82.

In 1981, ice conditions in the study area were first observed beginning 2 February, when signs of ice weakening became apparent following rainfall in excess of 50 mm (2 inches). By 24 February, ice cover within several kilometres of the intervale land (area east and west of Arbour Drive) had moved downstream and the threat of ice jamming within the study area had therefore diminished. Table 16 summarizes the ice conditions which existed at the gauge locations as break-up progressed during this period.

Graphical representations of the ice conditions existing along Rights and West Rivers and Brierly Brook on 3, 12 and 24 February, 1981 are depicted in Figures 5-2, 5-3 and 5-4, respectively. The break-up and conditions observed are partly based on interviews with local residents who report that break-up in 1981 was fairly typical of the manner in which ice generally moves in the study area.

The pattern of ice break-up in 1981 was as follows:

a) On 2 and 3 February, rainfall runoff fractured the cover on Brierly Brook. Some ice piling took place at one or two locations (e.g. below Church Street) but no flooding was reported. Ice on the Rights River and West River remained shorefast and consolidated through this period.

b) Rainfall and snowmelt during the week that followed led to a rapid rise in streamflow to a peak on 12 February. This peak fractured most of the ice on Brierly Brook and carried it downstream to the Church Street Bridge where it piled and jammed and blocked much of the opening.

TABLE 16

CHARACTERISTICS OF ICE RUNS OBSERVED

FEBRUARY 2 - 24 1981

Date	Location	Upstream of Structure	Through Structure	Downstream of Structure	Remarks
Feb 3	B1	intact	open	minor jamming	
	B2	collapsed but intact	intact	minor jamming	
	B3	open	jamming	open	slight backwater from jamming
	B4	intact	intact	partially open	crest gauge dislodged
	B6	partially open	ice frozen to stream bottom		flow metering not possible
	Dam	intact	N.A.	intact	no discharge
	R1	intact	intact	intact	no discharge
	R2	intact	intact	intact	flow along banks/flow metering not possible
	W1	intact	intact	intact	
	W2	intact/ collapsed	intact/collapsed	intact	
	W3	intact/ lifted	intact/lifted	intact	flow over ice/flow metering not possible
Feb 12	B1	jamming	jamming	jamming	staff gauge lost, localized flooding
	B2	open	open	open	crest gauge, staff gauge lost
	B3	open	open	open	staff gauge lost

TABLE 16 (Cont'd)

CHARACTERISTICS OF ICE RUNS OBSERVED

FEBRUARY 2-24, 1981

Date	Location	Upstream of Structure	Through Structure	Downstream of Structure	Remarks
	B4	intact	large ice flows lodged between abutments	open	flow metering not possible
	B6	open	open	open but ice stranded on banks	flow metering result 9.9 m^3/sec
	Dam	floating broken ice	N.A.	open	water surface elevation 19.2 m
	R1	intact	intact	intact	Interval covered with broken ice (Rights River side)
	R2	intact	intact	intact	
	R3	open	open	open	intermittent heavy movement of ice from upstream, flow metering not possible
	W1	intact	intact	intact	Interval relatively free of ice (West River side)
	W2	open	open	open	flow metering not possible
Feb 24	B1-B6 & Dam	open	open	open	water levels down.
	W2-W3	open	open	open	Stranded ice along banks
	R2-R3	open	open	open	
	W1-R1	open	open	open	heavy ice on interval 400 mm thick and up to 5.5 m diameter
	Habour				solid ice cover

All watercourses clear of surface ice well above the limits of the study area.

The ice pieces were between 30 and 38 cm (2.5 and 3.0 feet) in thickness and were evenly distributed in size from a maximum of about 3 m (10 feet) to a minimum of about 0.3 m (1 foot).

The ice jam at Church Street Bridge appeared to be composed of the largest ice pieces in contact with the bed of the stream and the bottom chord of the bridge. This caused flooding above the bridge, and a spill of flood waters and small ice cakes over Church Street. Fragmented ice was also piled at the confluence of Brierly Brook and the West River where the solid ice cover remained in place. Trees along the brook between the West River and Church Street also appeared to be discouraging movement of the ice onto the low lying area near the confluence known locally as the Salt Pond area (southern area bounded by the West River, Brierly Brook and Church Street). The ice backed up to the Church Street Bridge.

c) Break-up occurred at the same time on Rights River where ice cleared the river and proceeded downstream to the interval. The ice in the harbour remained intact, initiated a jam and caused the deposition of ice onto the intervale land just upstream of the CNR trestle as shown in Figure 5-4.

d) Ice in the West River remained intact through these two high-flow events. In the following two weeks, it appears to have decayed and weakened and by 24 February, the West River was also free of ice down to the harbour.

In summary, high flows in the winter of 1981 first influenced the ice cover on Brierly Brook. Upstream ice was carried down the brook to the West River and the Church Street Bridge where its passage was halted by the bridge and the ice cover on the West River. Ice jamming and flooding resulted at Church Street and below. Ice on the Rights River was carried downstream to the harbour where it jammed on the solid ice cover below the CNR bridge. This raised water levels and spilled ice harmlessly on the intervale. Ice on the West River remained consolidated and appears to have weakened and been carried away without incident.

Of principal interest for this study is the dry ice jam which formed at the Church Street Bridge and blocked between 60% and 90% of the opening of the bridge.

In 1982, break-up was first observed during the day on 4 February when rainfall and warm temperatures combined to increase streamflow through Antigonish. This initially caused some minor jamming on Brierly Brook and then later (that night) a significant jam and flood on the Rights River near the Main Street Bridge resulted. Break-up and ice-related flooding occurred again on both streams on 8 and 9 March, and again the more significant flooding occurred on the Rights River. Ice on the West River remained intact through both of these events and appears to have cleared without incident in late March or April.

Figures 5-5 and 5-6 summarize the observed ice conditions during these two events. The pattern of break-up in 1982 was as follows:

a) The ice cover on Brierly Brook broke away from the banks in some locations and began to slowly move downstream on 4 February. Short reaches of the brook became free of ice and short jams occurred below the Main Street Bridge across Brierly Brook and at the confluence with the West River. Jamming was not significant enough to lead to flooding and by the next morning the principal obstruction to flow on Brierly Brook was a mass of large ice pieces which had moved into the reach between the Church Street Bridge and the West River.

b) Runoff on the Rights River appears to have caused several small ice jams above Antigonish on 4 February which may have delayed the arrival of peak flows and upstream ice until late in the day and into the morning of 5 February. This ice did not drive through to the intervale and the harbour, however, as it usually does. Instead, it only carried through to the Main Street Bridge where the ice buckled and grounded and piled to within 0.5 m (1.6 feet) of the bottom chord of the bridge. The channel below the bridge contained a consolidated, shore-fast cover while the channel up to the Cloverville Bridge was completely filled with broken ice. This ice was about 30 cm (2.5 feet) thick and was composed of small broken pieces (30%) and floes which ranged in diameter from 30 cm (20%), 60 cm (40%) and 120 cm (10%).

This obstruction forced river levels to rise causing ice and water to spill over the western banks of the Rights River, across Main Street and into Columbus Field. Peak water level was observed to be about 5.09 m (16.7 ft)

upstream of the Main Street Bridge. Local newspaper reports considered this to be the worst flood in 30 years.

c) Ice on the West River remained consolidated in this period.

d) Cold weather and a reduction in streamflow and water levels returned on 5 February and consolidated the broken ice field on the bed of the Rights River. Soon after that, the EMO and Nova Scotia Department of the Environment cleared much of the ice from this section of the channel.

e) Heavy rainfall from 5 March to 7 March again broke up the ice on Brierly Brook at its mouth and at the Main Street Bridge, but there was no significant flooding. Ice on the Rights River jammed on bed-fast ice just below Cloverville Bridge and filled the channel through the Cloverville Bridge and upstream for a length of about 300 m. This accumulation was reported to be about 2.4 m (7.9 feet) thick and may have contacted the bottom chord of the bridge. Ice and water spilled over the west banks and inundated a trailer park off Brookland Street.

f) This jam on the Rights River was cleared by explosives and by 25 March the majority of the ice in this arm had melted or been carried downstream to the harbour.

In summary, streamflows in the winter of 1982 were sufficiently high to break up the ice on the Rights River and carry it downstream to Antigonish. Streamflows were not

unusually high, however, and it appears that ice jamming (February) was caused by too much ice in the channel as compared to a combination of a large discharge of ice and streamflow. The ice jam in March appears to have been initiated on residual, bed-fast ice remaining from the earlier jam and might have been much more severe if much of the ice from the earlier jam had not been removed from the channel.

Of considerable interest to the backwater study is that both ice jams on the Rights River appear to have been grounded on the river bed. In the February 1982 ice jam, almost 100% of the river discharge spilled over the channel and across Main Street and, in the March ice jam at Cloverville Bridge, 50% or more of the bridge's conveyance was lost due to ice blockage.

In addition to the observed conditions previously described, several townspeople familiar with historical flooding problems were interviewed in order to identify ice jam locations and to confirm the observed trends. Most of the local citizens interviewed confirmed the general trends in ice runs and ice jam locations but since their information was based on memories and opinions, it tended to be general and at times contradictory. There was general agreement, however, that the patterns of ice break-up and ice characteristics of February 1981 were similar to other years, although break-up occurred about a month earlier than usual.

All residents felt that the predominant location of ice jamming in the study area is the Church Street Bridge on Brierly Brook (B-1). Although this bridge appears to provide a small opening for the passage of ice, it was also felt that at least part of the problem resulted from the lack of

release for ice which has passed through the bridge and has contacted the intact ice downstream on the West River.

Ice jamming on the Rights River was considered (before 1982) to have been greatly reduced as a result of channelization between Cloverville Road (R-3) and the Main Street Bridge (R-2). Water levels, tides and streamflow in 1981 were such that ice could be carried out of the Rights River and be deposited on the intervale land. This is apparently not always the case, however, as evinced by the ice jam in 1982. It was suggested that part of the problem in the lower reaches of the study area (from R-2 to the mouth) is that ice freezes to the river bottom when tides and water levels are low or to islands or shoals near the CNR line. This ice and the consolidated ice in the harbour is difficult to dislodge when break-up occurs and acts as a barrier to ice moving downstream.

Ice jams are not reported to have been a frequent problem on the West River and have only been experienced at the old, two-span bridge at McAmis Street (W-2). None has been reported at the present, single span structure and the river remained free of ice jams above McAmis Street during the winters of 1980-81 and 1981-82. It has been suggested that break-up ice accumulations occur at the bend in the West River upstream of this bridge, but it is not known if a significant backwater condition was caused by this ice or if this ice was primarily supplied from Brierly Brook.

5.8 Tidal Effects

To assess the effect of tides on water levels in the study area, water levels were measured over a tidal cycle at the

CNR bridge (R-1) and Main Street Bridge (R-2) on the Rights River.

This survey was conducted on 5 June 1981 prior to low tide at 0600 hours (EST) and finishing at high tide at 1930 hours on the same day. The weather during the observations was fair, wind was calm and the flow in the river was about 25-30 m^3/s (880-1060 cfs). Staff gauge readings were taken at 15 minute intervals throughout the day at R-1 and at 30 minute intervals at R-2. During the field observations a 10 mm (0.4 inch) fluctuation in water level was measured at the Main Street bridge (R-2). Consequently, it became apparent that there was no measurable tidal effect at the Main Street bridge (R-2) on the day of observation.

The observed tides were compared to those predicted in Canadian Tide & Current Tables (1981) for Pictou, N.S. The observed tide levels were not available since the tide gauge malfunctioned on the day the observations were made. For the time of observation, the predicted high tide water level at Pictou was 1.0 m (3.28 feet) which was the yearly maximum.

Plots comparing observed water levels at the CNR bridge (R-1) to those predicted for Pictou are shown in Figure 5-7. As indicated in this figure, the high tide at the CNR bridge lags about 80 minutes behind the high tide at Pictou. Further discussion on applicable tide levels for this study is presented in Section 7.6.

CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

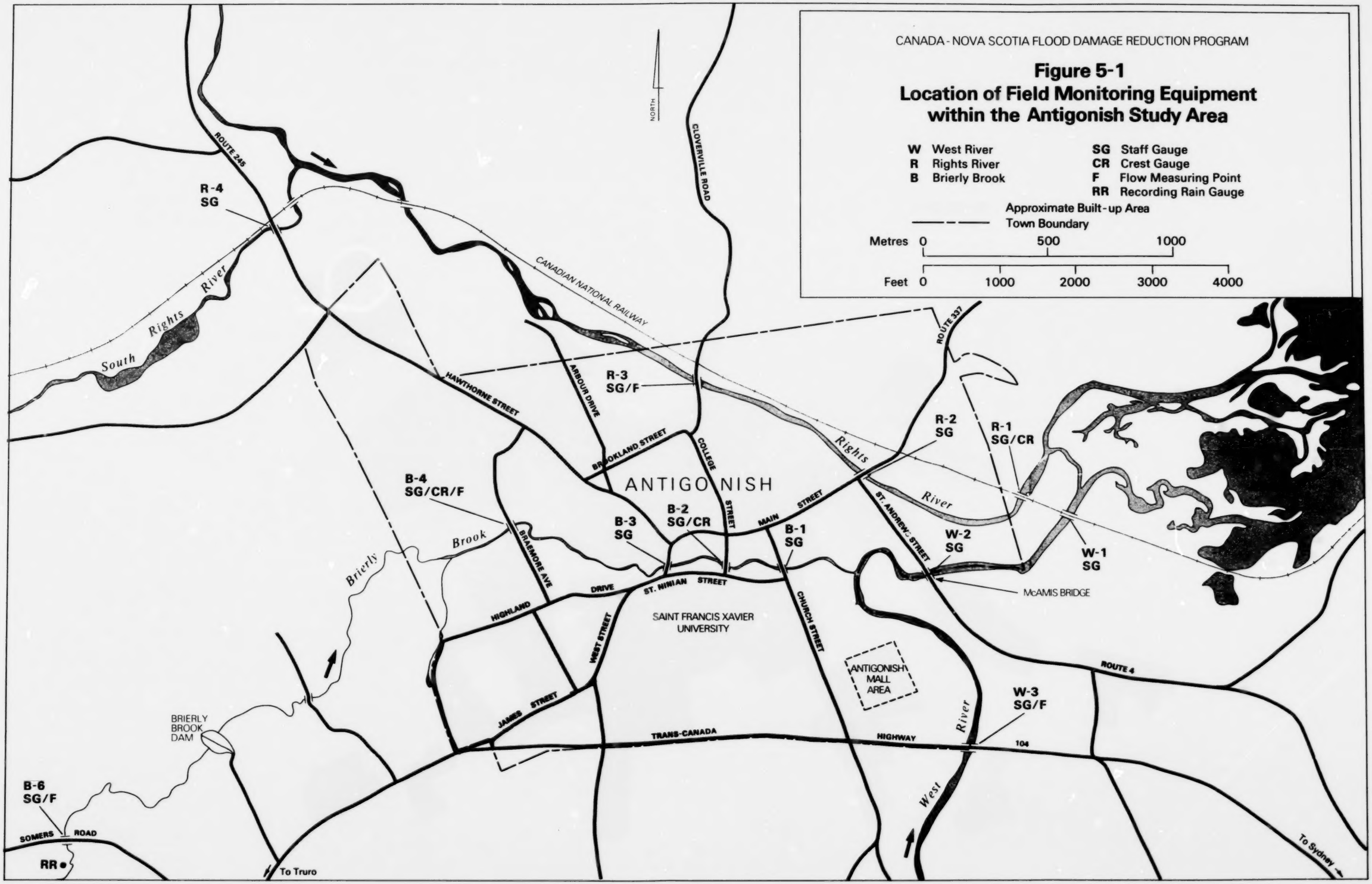
Figure 5-1
Location of Field Monitoring Equipment within the Antigonish Study Area

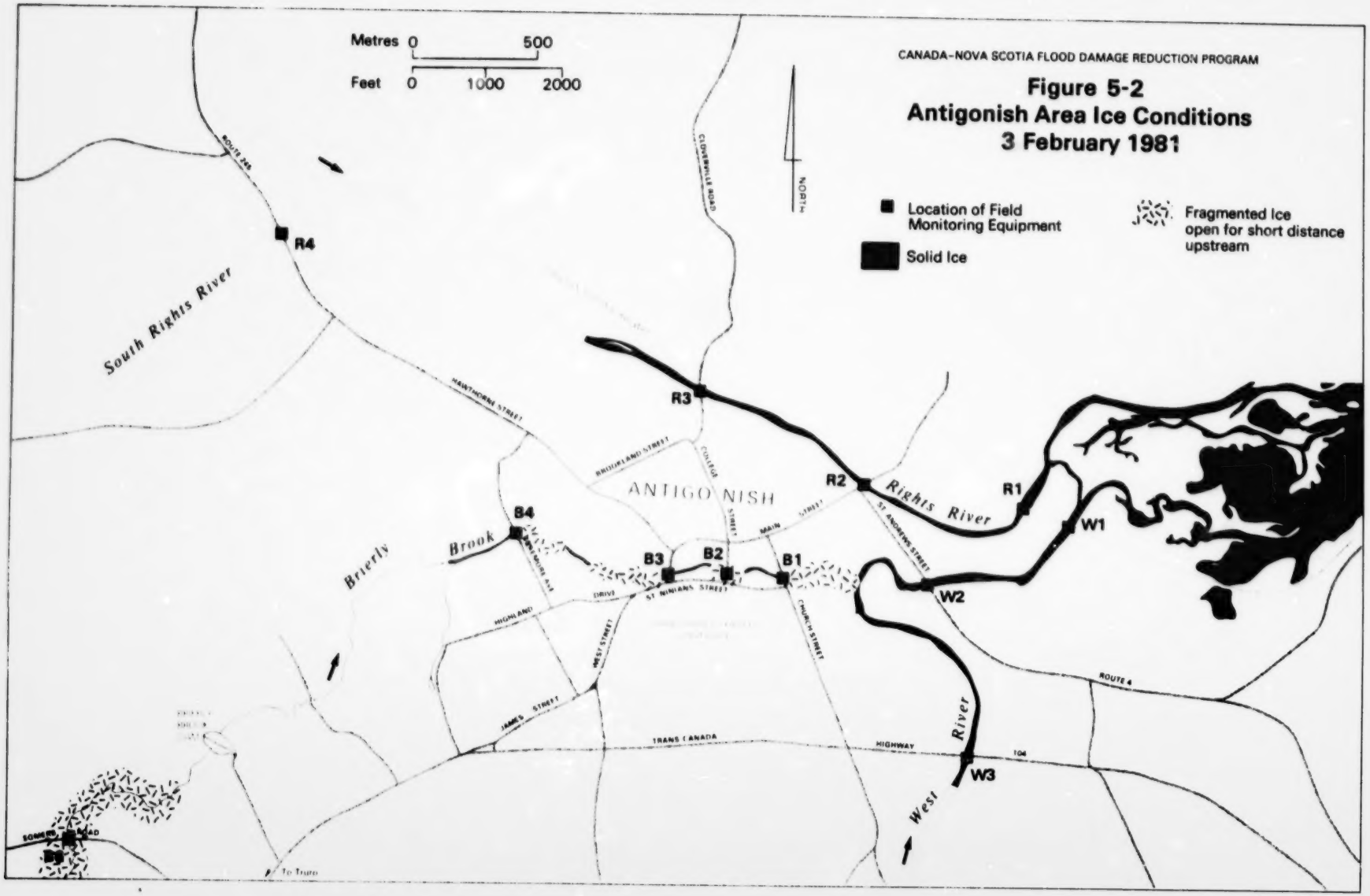
W West River
R Rights River
B Brierly Brook
SG Staff Gauge
CR Crest Gauge
F Flow Measuring Point
RR Recording Rain Gauge

Approximate Built-up Area
Town Boundary

Metres 0 500 1000

Feet 0 1000 2000 3000 4000

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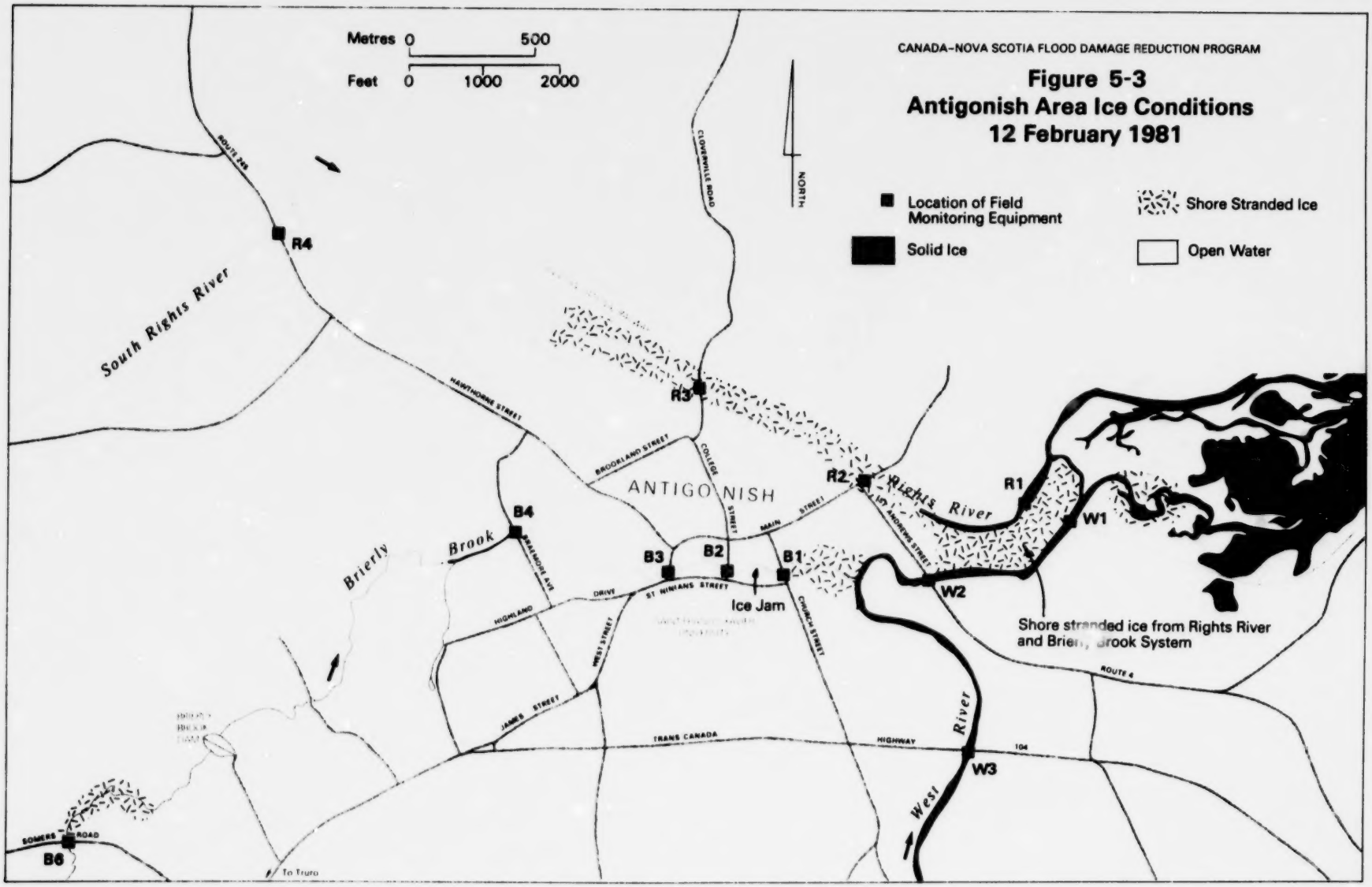
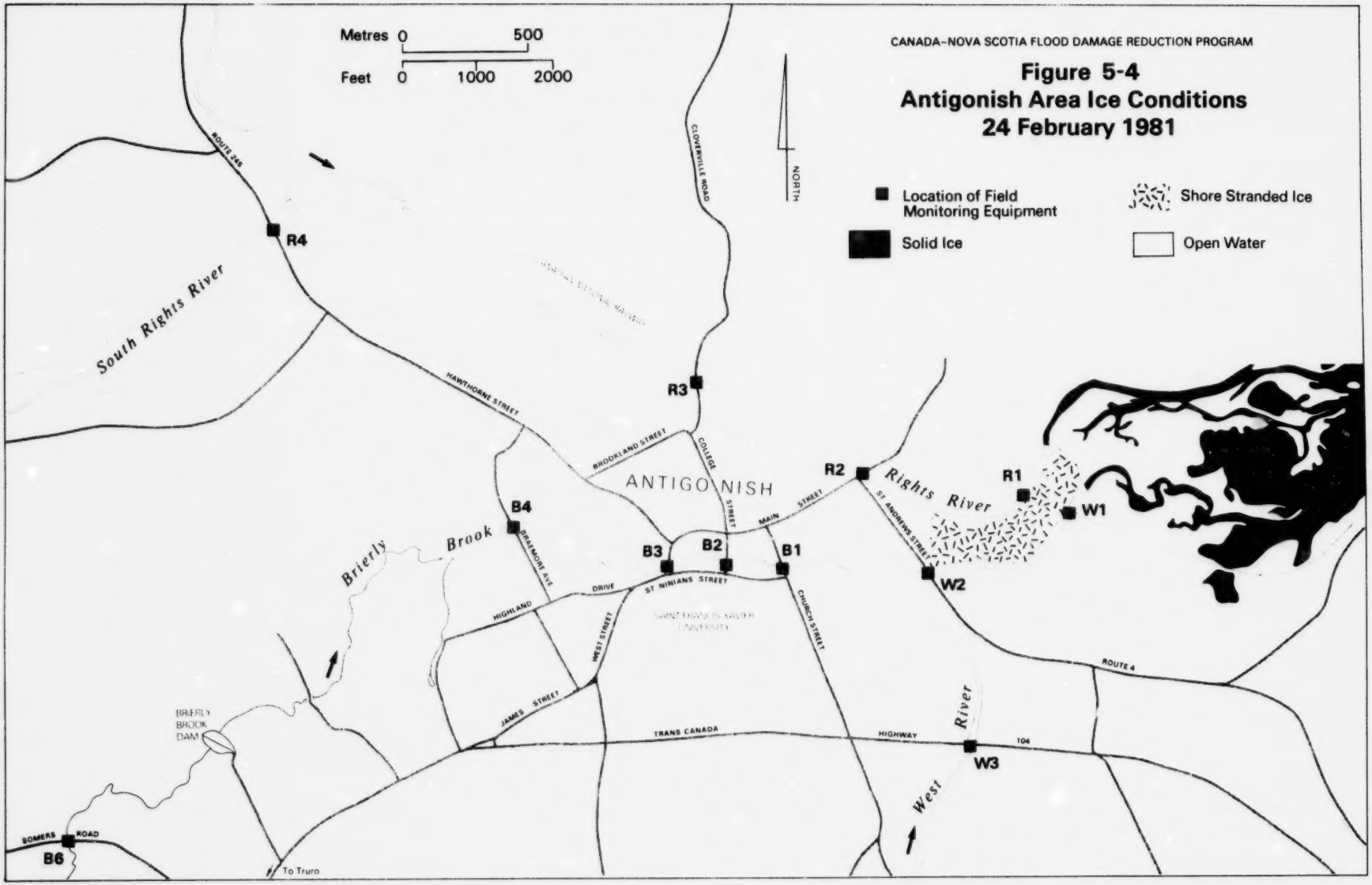
Feet 0 1000 2000
CANADA-NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM
Figure 5-2
Antigonish Area Ice Conditions
3 February 1981
Location of Field Monitoring Equipment
Solid Ice
Fragmented Ice open for short distance upstream
NORTH
South Rights River
Brierly Brook
ANTIGONISH
Rights River
West River
R1
R2
R3
R4
B1
B2
B3
B4
W1
W2
W3
ROUTE 4
TRANS CANADA HIGHWAY 104
To Truro

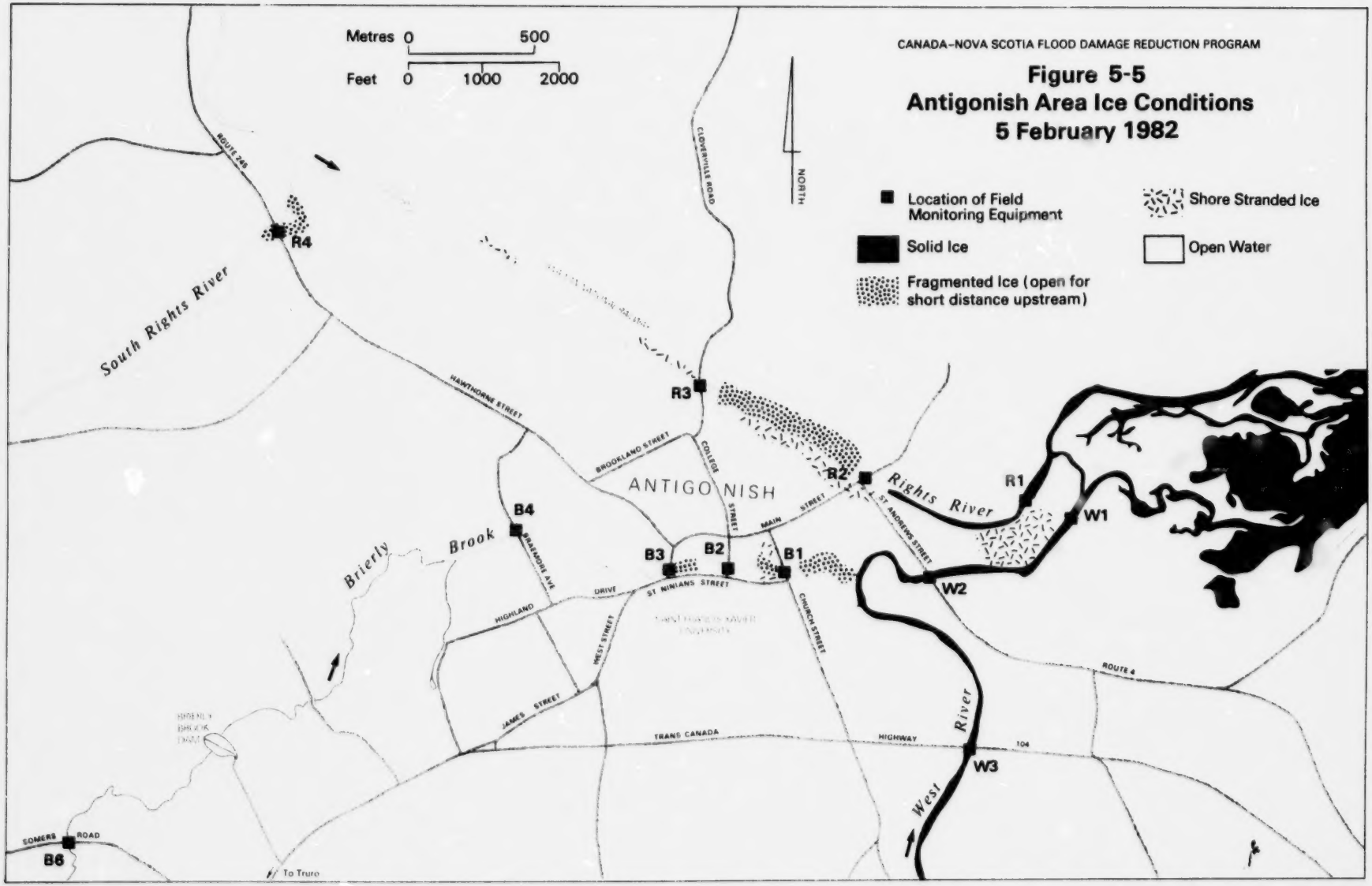
01194-0


Metres 0 500
Feet 0 1000 2000
NORTH
CANADA–NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM
Figure 5-3
Antigonish Area Ice Conditions
12 February 1981
Location of Field Monitoring Equipment
Shore Stranded Ice
Solid Ice
Open Water
R1
R2
R3
R4
B1
B2
B3
B4
B6
W1
W2
W3
South Rights River
Rights River
Brierly Brook
West River
ANTIGONISH
Ice Jam
Shore stranded ice from Rights River and Brierly Brook System
ROUTE 245
CLOVERVILLE ROAD
HAWTHORNE STREET
BROOKLAND STREET
COLLEGE STREET
MAIN STREET
ST ANDREWS STREET
ST NINIANS STREET
HIGHLAND DRIVE
CHURCH STREET
FRASER AVE
FRIEST STREET
JAMES STREET
TRANS CANADA HIGHWAY 104
ROUTE 4
SOMERS ROAD
To Truro

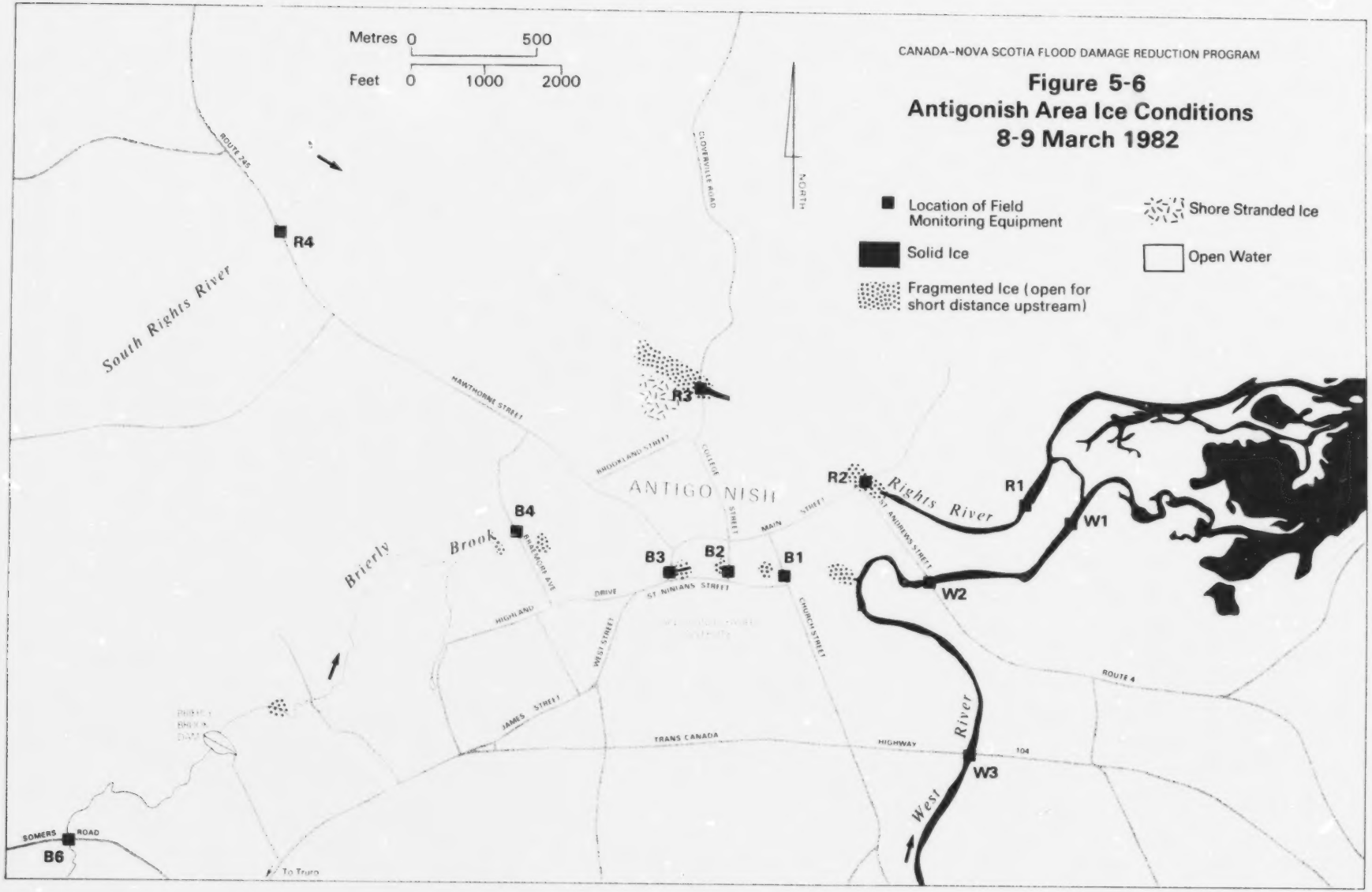
01194-0


CANADA–NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM
Figure 5-4
Antigonish Area Ice Conditions
24 February 1981
Metres 0 500
Feet 0 1000 2000
NORTH
Location of Field Monitoring Equipment
Solid Ice
Shore Stranded Ice
Open Water
R1
R2
R3
R4
B1
B2
B3
B4
B6
W1
W2
W3
South Rights River
Rights River
West River
Brierly Brook
ANTIGONISH
CLOVERVILLE ROAD
HAWTHORNE STREET
BROOKLAND STREET
COLLEGE STREET
MAIN STREET
ST ANDREWS STREET
ST NINIANS STREET
BRAEMORE AVE
DRIVE
HIGHLAND
WEST STREET
CHURCH STREET
JAMES STREET
TRANS CANADA HIGHWAY 104
ROUTE 4
ROUTE 245
BRIERLY BROOK DAM
SOMERS ROAD
To Truro

01194-0


Metres 0 500
Feet 0 1000 2000
NORTH
CANADA–NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM
Figure 5-5
Antigonish Area Ice Conditions
5 February 1982
Location of Field Monitoring Equipment
Solid Ice
Fragmented Ice (open for short distance upstream)
Shore Stranded Ice
Open Water
South Rights River
Brierly Brook
Rights River
West River
ANTIGONISH
ROUTE 245
CLOVERVILLE ROAD
HAWTHORNE STREET
BROOKLAND STREET
COLLEGE STREET
MAIN STREET
ST ANDREWS STREET
ST NINIANS STREET
BRAEMORE AVE.
DRIVE
HIGHLAND
WEST STREET
CHURCH STREET
JAMES STREET
TRANS CANADA
HIGHWAY
104
ROUTE 4
SOMERS ROAD
To Truro
R1
R2
R3
R4
B1
B2
B3
B4
B6
W1
W2
W3

01194–0


Metres 0 500
Feet 0 1000 2000
NORTH
CANADA–NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM
Figure 5-6
Antigonish Area Ice Conditions
8-9 March 1982
Location of Field Monitoring Equipment
Shore Stranded Ice
Solid Ice
Open Water
Fragmented Ice (open for short distance upstream)
South Rights River
Brierly Brook
Rights River
West River
ANTIGONISH
R1
R2
R3
R4
W1
W2
W3
B1
B2
B3
B4
B6
ROUTE 245
CLOVERVILLE ROAD
HAWTHORNE STREET
RIDGELAND STREET
COLLEGE STREET
MAIN STREET
ST ANDREWS STREET
ST NINIANS STREET
HIGHLAND DRIVE
WEST STREET
CHURCH STREET
JAMES STREET
TRANS CANADA HIGHWAY 104
ROUTE 4
SOMERS ROAD
To Truro

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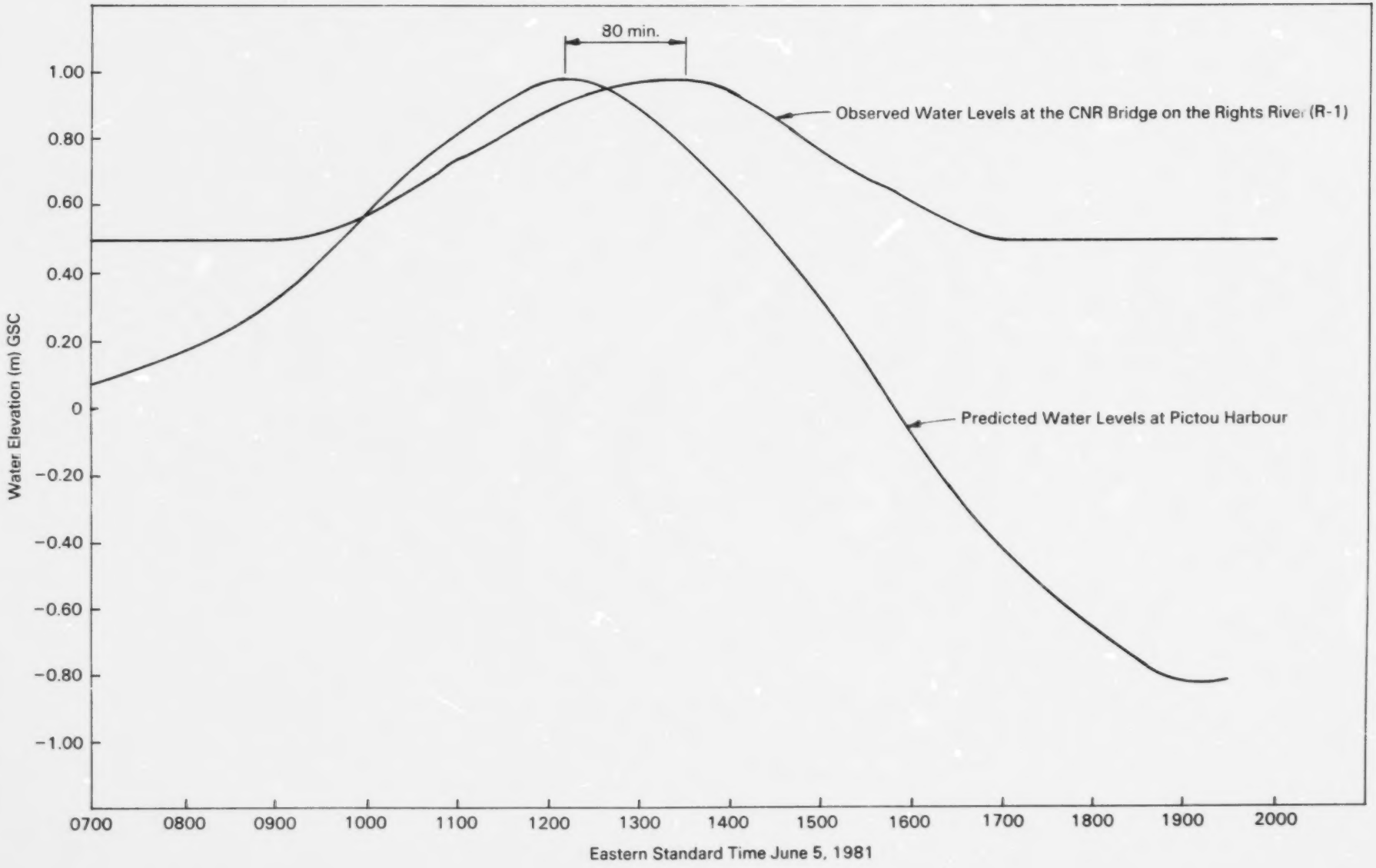
CANADA-NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Observed Tidal Cycle at the CNR Bridge on the Rights River on June 5, 1981

Figure 5-7



CHAPTER 6 - HYDROLOGIC ANALYSIS

6.1 General

In the recent Nova Scotia Regional Flood Frequency Analysis (Ref.14), estimates of the peak flows associated with floods for recurrence intervals of 1:20 and 1:100 years for various locations along the Rights and West Rivers and Brierly Brook were determined. The peak flow estimates for selected locations along the study reaches are summarized in Table 17, together with an estimate of their 95% confidence limits. An independent assessment of the values of the parameters used in the regression equations for Brierly Brook, Rights and West Rivers was undertaken. Although some discrepancy was noted in estimating some of the parameters, the values used seem reasonable. The discrepancy did not significantly affect the computed flows presented in the NSRFFA report. For the Rights and West Rivers, the 1:20 and 1:100 years instantaneous peak flows will be used to compute the corresponding backwater profiles. However for Brierly Brook the effect of the Brierly Brook Dam in reducing downstream flood peaks was not included in the Regional Flood Frequency Analysis. In that study it was recommended that peak flows estimated for Brierly Brook should be derived using an alternative technique. It was also recommended that the effects of peak flow attenuation by the Brierly Brook Reservoir should be included in the assessment of peaks at downstream locations.

Although hydrologic simulations were initially to be undertaken only for the Brierly Brook watershed, it was found necessary to carry out hydrologic simulations for the Rights River as well due to the lack of calibration data available

TABLE 17

PEAK FLOW ESTIMATES FOR THE STUDY AREA*

Flood Prone Area	Daily Mean Flow (QD m^3/s)			Instantaneous Peak Flow (Qp m^3/s)					
				1:2		1:20		1:100	
	1:2	1:20	1:100	QP	C.L.(%)**	QP	C.L.(%)	QP	C.L. (%)
6-1 Brierly Brook at Dam	11.8	24.4	33.8	30.2	+ 214,-68	62.3	+ 228,-70	86.6	+ 239,-70
6-2 Brierly Brook at West R. confluence	14.5	29.4	40.8	35.3	+ 190,-66	71.9	+ 205,-67	99.6	+ 215,-68
6-3 Rights River at Mouth	47.5	88.1	120.0	85.5	+ 91,-48	158.6	+ 106,-51	216.1	+ 117,-54
6-4 West R. above Brierly Brook Confluence	109.5	208.3	285.2	161.4	+ 58,-37	306.9	+ 75,-43	420.4	+ 87,-47
6-5 West R. below Brierly Brook Confluence	120.5	227.4	310.9	175.1	+ 56,-36	330.4	+ 74,-42	451.7	+ 86,-46

* Source: Regional Flood Frequency Study (ref. 14)

** 95% Confidence Limits as a Percentage of Flow.

Note: Flows derived for Brierly Brook in the Regional Flood Frequency Analysis (RFFA) do not take into account the reservoir effect from the Brierly Brook dam. Also, RFFA is not applicable to watersheds as small as Brierly Brook.

for Brierly Brook. Calibration results from the Rights River watershed were then used to calibrate the Brierly Brook hydrologic model.

In order to assess the applicability of the estimated flood peaks developed in the Regional Flood Frequency Analysis and to evaluate the effects of peak flow attenuation by the Brierly Brook Reservoir, the HYMO model (Ref. 21) has been applied to the Brierly Brook watershed. The HYMO model has been selected to examine the flood discharge characteristics of the Brierly Brook watershed because of the following features which it contains:

- Soil complex numbers for deriving rainfall-runoff amounts (combines the effect of soil types, soil moisture and land use characteristics)

- Flows from several subwatersheds can be modelled and can account for the difference in timing of runoff and arrival of flood peaks at the point of interest

- Accounts for natural channel and flood plain storage resulting in hydrograph attenuation

- Accounts for the effects of reservoir routing on downstream flood peaks.

Full details of the HYMO model and its underlying theory are given in the users manual (Ref. 21). Nevertheless, a number of basic components are briefly documented in the following section as background for the discussion of model calibration.

6.2 The HYMO Model - A Brief Description

The HYMO model is a single event simulation model which was developed to estimate surface runoff and sediment yield from watersheds. Rainfall data is transformed into runoff hydrographs and subsequently routed through stream valleys or reservoirs. Since the model is written in a problem oriented language, very little knowledge of computer programming is required for its use.

The watershed parameters utilized in the HYMO model are estimated by using topographic and hydrologic information as well as additional data collected as part of the field monitoring program. This information is used to calibrate and validate the HYMO model for the Brierly Brook watershed.

In analyzing a study watershed for HYMO analysis, the watershed is broken down into subareas corresponding to the number of points at which flow estimates are required. The runoff volume for each subarea is computed by the U.S. Soil Conservation Service (S.C.S.) Curve Number (CN) method (Ref. 25). This volume is distributed in time using a unit hydrograph to obtain a hydrograph from each subwatershed. The unit hydrograph consists of three parts:

i) From the start of the rise to the inflection point on the recession limb, a two parameter gamma distribution equation is used. The two parameters are the time to peak (tp) and recession constant (k).

ii) From the inflection point to 2k units in time past the inflection point a simple exponential decay equation with parameter k is used.

iii) From a point in time 2k units past the inflection point to infinity a simple exponential decay equation with parameter 3k is used.

When the model is applied at an ungauged sub-watershed, the appropriate values for the two parameters, time to peak (tp) and recession constant (k), are most commonly estimated from empirical relationships which relate to major physiographic characteristics. Since these empirical relationships are based on Texas experience, it is desirable to calibrate the model before it can be used to accurately predict the response of a watershed.

Channel routing of flow hydrographs is accomplished using the Variable Travel Time method. This is a non-linear procedure which adjusts travel time through a reach to account for the increasing velocity of flow as the depth of flow increases. In order to utilize this method the slope and length of the reach must be specified with a 'typical' valley channel cross-section; the only parameters which must be estimated are values of Manning's "n" for the flood plain and for the channel.

In summary the model is easy to use, flexible and parameter efficient requiring only three parameters (tp, k and CN) per subarea and three parameters (valley cross-section, slope and length) per channel routing section.

6.3 Set-up of the HYMO Model

6.3.1 General

As in the case of all existing hydrologic models, HYMO is a simplified representation of the real world. Empirical equations and established guidelines are available to estimate the parameters of the model; however, the best approach in assuring that the model will give realistic flow estimates is to calibrate the model using observed data. As discussed in Section 5.0, a field monitoring program was established to collect precipitation, discharge and water level data. The field program was implemented to collect data for the calibration and validation of the hydrologic and hydraulic models since historical data were inadequate.

According to the terms of reference for the study, the HYMO model was to be set up only for the Brierly Brook watershed. However, during the course of the field monitoring progam, major flood producing events did not occur. High flows were observed within the study reaches, but as outlined in Section 5.6, it was not possible to measure the peak flow discharge rates for the calibration and validation of the hydrologic and hydraulic models.

In the absence of adequate calibration/validation data for Brierly Brook, it was necessary to supplement the data collected with other data from adjoining watersheds. Since the Rights River is gauged and appears to have similar physiographic characteristics to the Brierly Brook watershed, the HYMO model was also set up for the Rights River. The Rights River hydrologic model was then used to estimate the hydrologic parameters for the calibration of the Brierly Brook model.

6.3.2 Estimates of Input Characteristics

The HYMO model was set up for both the Brierly Brook and Rights River watersheds. To estimate the necessary hydrologic parameters, each watershed was divided into sub-catchment areas as shown in Figure 6-1. The physical parameters and the pre-calibration estimates of the model parameters for the Brierly Brook and Rights River sub-catchment areas are shown in Table 18 and Table 19 respectively. The initial estimates of the time to peak (tp) and the recession time (k) parameters are based on the empirical relationships (Ref. 21) given in the HYMO users manual. These estimates were later modified based on the calibration of the HYMO model as outlined in Section 6.4.

Physical parameters of the two watersheds were obtained from 1:50 000 topographic mapping supplemented with other available mapping where possible. The location of valley sections, flow points and other pertinent information is also shown in Figure 6-1.

Hydrologic soil-cover complexes were derived for each sub-catchment area by analyzing the combined effect of the soil types, vegetal cover and land use characteristics. The soil types for each sub-catchment area were obtained from a report on the soil survey of Antigonish County (Ref. 25). Land use and vegetal cover information were obtained from available maps and aerial photographs. Each complex was expressed in the form of a Curve Number (CN) which reflects the potential volume of runoff during a storm. Full details of the derivation of the hydrologic soil-cover complexes may be obtained from the Soil Conservation Service Handbook (Ref. 27). Pertinent information relating to the soil types, land use and

TABLE 18

SUB-CATCHMENT AREA HYDROLOGIC PARAMETERS
FOR THE BRIERLY BROOK WATERSHED

Sub-Catchment Area I.D.	Drainage Area (km^2)	Average Channel Gradient (m/km)	Pre-calibration Estimation of Time to Peak (tp) (hrs)	Pre-calibration Estimation of Time to Recede (k) (hrs)
301	7.9	53.1	0.60	0.45
302	14.1	9.9	1.65	2.0
303	4.2	3.8	1.40	2.60
304	5.4	3.8	0.80	0.95
305	1.6	3.8	0.90	2.3

TABLE 19

SUB-CATCHMENT AREA HYDROLOGIC PARAMETERS
FOR THE RIGHTS RIVER WATERSHED

Sub-Catchment Area I.D.	Drainage Area (km^2)	Average Channel Gradient (m/km)	Pre-calibration Estimation of Time to Peak (tp) (hrs)	Pre-calibration Estimation of Time to Recede (k) (hrs)
301	35.5	25.3	1.5	1.2
302	25.0	8.78	2.1	2.2
303	28.2	25.2	1.3	1.1
304	20.8	12.0	1.4	1.3
305	8.6	9.5	1.3	1.9
306	3.3	6.0	1.0	1.9
307	7.8	27.3	0.9	0.9

CN values for the Brierly Brook and Rights River sub-catchment areas are shown in Tables 20 and 21 respectively.

6.4 Model Calibration and Validation

6.4.1 General

Based on the discharge data collected during the field monitoring program, it was decided to use the November 1981 storm event for calibration and the May 1981 and May 1982 storm events for validation of the HYMO model for the Rights River watershed. As discussed previously, discharge data are not available for Brierly Brook for the May 1981 and May 1982 storm events. Consequently it was not possible to validate the Brierly Brook hydrologic model. Results from the validated Rights River model were then used to calibrate the Brierly Brook model.

6.4.2 Establishment of Antecedent Soil Moisture Conditions

The antecedent soil moisture conditions under average conditions (AMC II) have been established as presented in Tables 20 and 21. However, soil moisture conditions need to be determined prior to a storm event so that the volume of runoff and peak flow can be calculated.

The soil moisture conditions (indicated by the CN value) can be determined using the S.C.S. Runoff Equation (Ref. 27) presented below:

TABLE 20

PRE-CALIBRATION HYDROLOGIC SOIL-COVER COMPLEXES
FOR THE BRIERLY BROOK WATERSHED

Sub-catchment Area I.D. *	Soil Type	Land Use	Weighted Curve Number (CN) (Average Antecedent Moisture Condition (AMC II))
301	Thom (80%) Queens (10%) Misc. (10%)	Forestry (100%)	63
302	Thom (55%) Queens (20%) Millbrook (15%) Misc. (10%)	Forestry (85%) Open Area (15%)	64
303	Queens (51%) Millbrook (21%) Stewiacke (21%) Misc. (7%)	Forestry (60%) Open Area (40%)	69
304	Queens (100%)	Forestry (40%) Open Area (50%) Urban (10%)	69
305	Urban (55%) Queens (45%)	Urban (55%) Open Area (40%) Forested (5%)	84

* Refer to Figure 6-1

TABLE 21

PRE-CALIBRATION HYDROLOGIC SOIL-COVER COMPLEXES
FOR THE RIGHTS RIVER WATERSHED

Sub-catchment Area I.D.*	Soil Type	Land Use	Weighted Curve Number (CN) (Average Antecedent Moisture Condition (AMC II))
301	Westbrook (80%) Queens (15%) Herbert (5%)	Forestry (90%) Open Area (10%)	61
302	Westbrook (70%) Queens (30%)	Forestry (85%) Open Area (15%)	61
303	Westbrook (100%)	Forestry (95%) Open Area (5%)	60
304	Westbrook (85%) Herbert (10%) Stewiacke (5%)	Forestry (85%) Open Area (15%)	61
305	Westbrook (80%) Stewiacke (15%) Herbert (5%)	Forestry (60%) Open Area (35%) Urban (5%)	65
306	Queens (60%) Stewiacke (40%)	Urban (50%) Open Area (40%) Forestry (10%)	83
307	Westbrook (85%) Queens (10%) Herbert (5%)	Urban (30%) Forestry (70%)	72

* Refer to Figure 6-1

$$Q = \frac{(P - 0.2\ S)^2}{P + 0.8\ S}$$

where Q = direct runoff volume (inches)
P = storm precipitation (inches)
S = soil moisture deficit (inches)

From the above equation, the "S" value can be computed since "P" is usually known and "Q" can be measured from a recorded hydrograph. The Curve Number (CN) can then be computed from the following equation developed by the S.C.S.:

$$CN\ (\text{Curve Number}) = \frac{1000}{10 + S}$$

The above procedure was used to investigate whether or not the antecedent soil moisture conditions for the Rights River and Brierly Brook watersheds are fairly uniform. The stream gauge on the Rights River measures the runoff from a drainage area which has similar hydrologic soil types and land use characteristics to the drainage area above the South River at the St. Andrews stream gauge (see Figure 2-2). The CN values prior to two storm events were determined for the two watersheds and found to be relatively close. Consequently, the antecedent soil moisture conditions for the South River, Rights River and Brierly Brook watersheds were assumed to be quite similar for the sub-catchment areas having similar CN values.

The antecedent soil moisture conditions for other sub-catchment areas exhibiting different CN values (AMC II) were adjusted based on the ratio of the "S" values corresponding

to the computed CN value for the storm event to that computed for AMC II for each sub-catchment area.

6.4.3 Calibration of the Rights River and Brierly Brook HYMO Models

The Rights River and Brierly Brook hydrologic models were calibrated based on the rainfall and discharge data collected during the November 1981 storm event described in Section 5.6.

Rights River

The rainfall amounts recorded at Collegeville, Antigonish and the tipping bucket raingauge (see Figure 5-1) seem to indicate that the rainfall was fairly variable over the Antigonish area. A rainfall isohyetal analysis was undertaken based on the available rainfall data. Unfortunately, there was no known rainfall information available from the northern part of the Rights River watershed. Based on this analysis, approximately 87.6 mm (3.45 in) of rain likely fell over sub-catchment area 301, 302 and 303 (refer to Figure 6-1) as compared with 70.4 mm (2.77 in) of rain recorded at the tipping bucket raingauge. The areal mean rainfall over each sub-catchment area was then determined and used as input to the HYMO model at 15 minute intervals.

The rainfall recorded at the tipping bucket raingauge was initially used in the HYMO model but it was found to produce low runoff volume and low peak flow. Based on the above analysis, it seems reasonable to assume that the rainfall that fell at the headwaters of the Rights River was greater than that recorded at the tipping bucket recording raingauge.

The appropriate CN values corresponding to the antecedent soil moisture conditions were then established based on the observed hydrograph at the Rights River streamflow gauging station and the 87.6 mm (3.45 in) of rain established as having occurred over the sub-catchment areas above the gauging station. The k and tp values presented in Table 19 were then adjusted to obtain the shape and peak of the observed hydrograph.

It was found that the k and tp values had to be increased to the values shown in Table 22 to obtain good calibration results. The k and tp values presented in Table 19 had to be multiplied by approximately 1.9 and 1.8, respectively so that the calibration results are in close agreement with th observed hydrographs.

The results of the calibration are shown in Figure 6-2. The simulated peak flow at the mouth of the Rights River was approximately 142 m^3/s (5015 cfs).

Brierly Brook

Since a complete flow hydrograph was not available for Brierly Brook, for the November 1981 storm, similar antecedent soil moisture conditions were used for the Brierly Brook watershed as that established for the Rights River. The k and tp values for Brierly Brook were also increased by approximately the same ratios as those for the Rights River. The model was then run with the 70.4 mm (2.77 in) of recorded rainfall as input.

The results of the simulations are shown in Figure 6-3. After increasing k and tp by 1.9 and 1.8 respectively, some

TABLE 22

CALIBRATED k AND tp VALUES FOR THE RIGHTS RIVER
AND BRIERLY BROOK WATERSHEDS BASED ON NOVEMBER 1981 STORM EVENT

Sub-Catchment Area	Brierly Brook			Rights River		
	k (hrs)	tp (hrs)	Adjusted CN Values	k (hrs)	tp (hrs)	Adjusted CN Values
301	0.8	1.0	80	2.2	2.8	79
302	3.8	3.1	80	4.2	3.7	79
303	4.8	2.5	84	2.1	2.4	79
304	1.6	1.3	84	2.4	2.4	79
305	4.1	1.55	97	3.5	2.3	82
306				3.6	1.8	92
307				1.6	1.6	86

further minor adjustments were made to the k and tp values to fine tune the calibration. The calibrated values are also presented in Table 22. As it can be seen from Figure 6-3, the simulated outflow hydrograph at the outlet of the Brierly Brook dam is in close agreement with the calculated outflows derived from the observed water levels.

Assessment of the effect variations in the stage-discharge relationship and the stage-storage relationship would have on the downstream flows and water levels is important because these relationships could be erroneous or altered by man or nature. For instance, the low level outlet could be blocked by ice or debris, the high level outflow could be broken allowing greater discharge than expected, and silting or ice could change the storage volume. Alternative stage-discharge relationships were derived by increasing and decreasing discharge by 10% from the calculated values shown on Figure 3-1. Similarly, alternative stage-storage relationships for $\pm$ 10% variations in storage for a given stage were prepared.

Simulation runs were made with the computer which indicated that changes in the stage-discharge curve caused a 0.3 m variation in water levels in the reservoir, whereas variation in the stage-storage curve had negligible effect on water levels in the reservoir.

6.4.4 Validation of the Rights River HYMO Model

The Rights River HYMO model was validated for the May 1981 and May 1982 storm events described in Section 5.6. The k and tp values used during the calibration exercise were maintained for each sub-catchment area. The antecedent soil

moisture conditions were computed as outlined in Section 6.4.2. The k, tp and adjusted CN values for the May 1981 and May 1982 storm events are presented in Table 23. Since the recorded rainfall amounts for this event were found to be fairly uniform throughout the Antigonish area no adjustment to the rainfall was made.

The hydrologic simulations were carried out and the results are shown in Figures 6-4 and 6-5 for the two events. As can be seen, the timing and peaks for the two simulated hydrographs are fairly close to the observed. Consequently, the HYMO model for the Rights River can be considered to be a fairly accurate representation of the watershed's response to a rainfall event. Although the Brierly Brook HYMO model could not be verified, the factors used to adjust k and tp based on the Rights River calibration seem to produce a fairly good calibration for the November 1981 storm event (Figure 6-3).

In conclusion, it can be stated that, based on the available rainfall and discharge data, the HYMO model set up for the Rights River and Brierly Brook watersheds can be expected to provide reliable flow estimates. However, the simulated Rights River flow will be used only for comparison purposes to the RFFA flows and will not be used in the hydraulic computation of flood elevations.

6.5 Hydrometeorological Data for Design Storms

6.5.1 Source of Hydrometeorological Data

In order to obtain the required rainfall data to derive the specified 1:20 yr and 1:100 yr return period flows for

TABLE 23

PARAMETERS USED IN THE CALIBRATION
OF THE RIGHTS RIVER HYMO MODEL
FOR THE MAY 1981 AND MAY 1982 STORM EVENTS

Sub-Catchment Area (ID)	k (hrs)	tp (hrs)	Adjusted CN Values for May 1981 Storm Event	Adjusted CN Values for May 1982 Storm Event
301	2.2	2.8	85	87
302	4.2	3.7	85	87
303	2.1	2.4	85	87
304	2.4	2.4	85	87
305	3.5	2.3	87	89
306	3.6	1.8	94	95
307	1.6	1.6	91	92

Brierly Brook, recorded rainfall data is required. In the Antigonish area, this data is not available. Short term (1970-1974) recording rainfall data is available for the Copper Lake station located about 24 km (15 miles) south of Antigonish. However, the A.E.S. requires at least seven years of record before a reliable intensity-duration-frequency (IDF) analysis can be carried out.

The nearest rate of rainfall station to Antigonish with sufficient record is the Truro station (see Figure 4-1). Since there is no other station with sufficient record and, as indicated in Section 3.1, the isohyetal patterns of peak rainstorm amounts in the Antigonish area are similar to those in the Truro area, the Truro rainfall data is considered to be applicable in the Antigonish area.

6.5.2 Storm Rain Distribution

The A.E.S. has developed 1-hour and 12-hour storm rain distributions for Truro as shown in Figures 4-2 and 4-3. Although the 24-hour storm distribution has not yet been developed, discussions with A.E.S. (Ref. 28) indicate that the distribution for the 24-hour duration is similar to the 12-hour. In order to compare the 1-hour and 12-hour distributions, the 50% curves were plotted as shown in Figure 6-6 with the storm duration reduced to a dimensionless scale. The 12-hour storm rain distribution for the Canadian East Coast as developed in the Flood Hydrology Guide for Canada (Ref. 29) is also presented for comparison purposes. As can be seen, the three distributions are quite similar.

From the results shown in Figure 6-6, it was assumed that the distributions for the 3-hour and 6-hour durations would also

be similar. Consequently, the various storm durations have similar precipitation time distributions.

6.5.3 Critical Storm Duration

The storm distributions described above were used to distribute in time the 100 year Truro rainfall for the 3-, 6-, 12- and 24-hour storm durations. The rainfall data was then used as input to the calibrated HYMO model for the Brierly Brook watershed. To determine the critical storm duration, that is, the one that produces the highest peak flow, the antecedent soil moisture conditions and the hydrologic parameters were maintained the same for all storm durations considered.

The HYMO model for Brierly Brook was run for both natural and regulated conditions. In both cases, the 6-hour storm duration produced the highest peak flows at the mouth of Brierly Brook. Although the 24-hour storm duration produced higher outflows at the dam due to its higher volume of runoff and storage, the contribution from the area downstream of the dam was such that the 6-hour storm duration produced the higher peak flow. Consequently, the 6-hour storm was adopted as the critical storm duration.

Similar analyses were carried out for the Rights River hydrologic model. For this watershed, the 6-hour storm duration also produced the highest peak flow at the mouth of the Rights River. Consequently, for this watershed the 6-hour storm was adopted as the critical storm duration.

6.6 Flow Simulations

6.6.1 General

Prior to utilizing the calibrated model to produce peak flow estimates for the 1:20 and 1:100 year events, it was necessary to establish the appropriate design meteorologic inputs. Since these inputs may be either rainfall or a combination of rainfall-and-snowmelt, each condition had to be analyzed to determine which produces the greatest peak flow.

Annual maximum daily precipitation was investigated based on 64 years (1917-1980) of record for the Collegeville station. The monthly occurrence of the annual maximum daily precipitation events in the 64 years is presented in Table 24. Also shown in Table 24 are the percentages by month of annual maximum daily discharge occurrences for 33 years of record (1917-1933, 1965-1980) for the South River at St. Andrews. This table indicates that the incidence of maximum annual precipitation and discharge in the Antigonish area is higher during the period from September to December inclusive, than the January to August period.

The derivation of the intensity-duration-frequency (IDF) curves for the rainfall and rainfall-and-snowmelt conditions is discussed in the following section.

6.6.2 Design Meteorological Inputs

As discussed in Section 2.5, flooding in the Antigonish area can, and has occurred at any season due to high rainfall. Some seasons are more likely than others due to frozen ground and snow which can melt and run off. In this section, peak

TABLE 24

MONTHLY OCCURRENCE OF ANNUAL MAXIMUM DAILY PRECIPITATION AND DISCHARGE IN THE ANTIGONISH AREA

Time	Monthly Percent of the Occurrence of the Annual Maximum Daily Precipitation (64 Years of Record)*	Monthly Percent of the Occurrence of the Annual Maximum Daily Discharge (33 Years of Record)**
January	12.1	10.7
February	5.2	3.6
March	1.7	7.1
April	0	3.6
May	5.2	3.6
June	5.2	3.6
July	6.9	3.6
August	10.3	7.1
September	17.2	7.1
October	13.8	10.7
November	15.5	17.9
December	6.9	21.4
Total	100%	100%

* Using Collegeville station as a basis

** Using South River at St. Andrews as a basis

flows associated with rainfall and rainfall-and-snowmelt events will be considered. In Section 6.8, peak flows associated with ice jams will be discussed.

Short duration rainfall intensity-duration-frequency data for Truro were obtained from the A.E.S. The 1:20 and 1:100 year annual IDF curves are presented in Figure 6-7. As indicated in Table 24, the incidence of maximum annual precipitation and discharge in the Antigonish area is highest during the period from September to December. Consequently, the annual IDF curves were used as the meteorologic inputs for this period.

From the annual IDF curves, it was obtained that for 6-hour storm duration, the 1:20 and 1:100 year rainfall amounts are 68.0 mm (2.68 in) and 88.4 mm (3.48 in) respectively.

Short duration rainfall IDF data was also obtained for the months of February, March and April. Rainfall-and-snowmelt IDF curves were derived for these months using the techniques described in Appendix "e" of this report. It was found that the April rain-and-snowmelt IDF curves produced higher intensities for similar durations and frequencies than the February and March events; consequently, the April IDF curve was adopted as the governing design event for the spring period.

6.6.3 Expectation Peak Flow Simulations

Brierly Brook

Since the HYMO model is a single event simulation model, it was necessary to determine the antecedent soil moisture

conditions prior to peak flow simulations for the 1:20 and 1:100 year events. To establish these conditions, annual maximum daily discharge events were selected from the 33 years of streamflow record for the South River at St. Andrews. This station was felt to be representative of the soil moisture conditions in the Antigonish area for the reason previously given in Section 6.4.2. The methodology outlined in Section 6.4.2 was used to back-calculate the appropriate antecedent soil moisture conditions (Curve Numbers) for selected storm events. From the selected events, it was found that the average CN value for the South River watershed above St. Andrews during the period from September to December was approximately 86. This CN value was then used to adjust the CN values for the Brierly Brook and Rights River sub-catchment areas. The adjusted k, tp and CN values used in the peak flow simulations for Brierly Brook are presented in Table 25.

Due to the uncertainty in the snowmelt contribution during rain-and-snowmelt events, the CN values derived for the spring period were considered not to be very reliable. Consequently for the April flow simulations, very wet antecedent soil moisture conditions (CN values greater than 95) were used to obtain conservative peak flow estimates. Appropriate antecedent soil moisture conditions were established for the various Brierly Brook sub-catchment areas for the September-December period and the April period. Flow simulations were then undertaken using the 6-hour storm duration with the appropriate 1:20 and 1:100 year rainfall and rainfall-and-snowmelt amounts using the storm distributions shown in Figure 6-6. From these simulations it was evident that the annual curve produced higher peak flows. Consequently the annual curve was adopted as the governing design condition.

TABLE 25

MODEL PARAMETERS USED IN THE
PEAK FLOW SIMULATIONS FOR BRIERLY BROOK

Sub-Catchment Area (ID)	k (hrs)	tp (hrs)	Adjusted CN Values
301	0.8	1.0	88
302	3.8	3.1	88
303	4.8	2.5	90
304	1.6	1.3	90
305	4.1	1.55	96

A summary of the 1:20 and 1:100 year peak flows at the various locations along Brierly Brook, with and without the effect of the Brierly Brook Dam, is presented in Table 26. The peak flows given in the Regional Flood Frequency Analysis without the effect of the dam are also presented for comparison with the simulated peak flows.

Table 26 indicates that the simulated peak flows are low in comparison to the RFFA flows. However, as will be discussed in Section 6.7.1, the estimated recurrence interval of Hurricane Beth for Brierly Brook using the simulated 1:20 and 1:100 year flows was found to be consistent with the recurrence interval established for Hurricane Beth on adjacent watersheds based on observed flow records.

Rights River

Prior to carrying out peak flow simulations for the Rights River watershed, the k, tp and CN values were adjusted as presented in Table 27.

The flow simulations for the Rights River watershed were carried out similarly to those for Brierly Brook. In consultation with the A.E.S., the 1:20 and 1:100 year rainfall amounts were reduced to 93% for the Rights River watershed to account for the areal distribution over the larger drainage area.

As was the case for Brierly Brook, the annual rainfall produced higher peak flow at the mouth of the Rights River than the April rain-and-snowmelt event. Consequently, the annual curve was adopted as the governing design condition for the Rights River watershed.

TABLE 26

SUMMARY OF PEAK FLOWS FOR BRIERLY BROOK

Location	Flow Point Number*	1:20 Year Instantaneous Peak Flow m^3/s (cfs)			1:100 Year Instantaneous Peak Flow m^3/s (cfs)		
		Simulated With Brierly Brook Dam	Simulated Without Brierly Brook Dam	Regional Flood Frequency Analysis	Simulated With Brierly Brook Dam	Simulated Without Brierly Brook Dam	Regional Flood Frequency Analysis
Brierly Brook at Dam (inflow into reservoir)	102	40.0 (1412)	40.0 (1412)	62.3 (2200)	55.4 (1955)	55.4 (1955)	86.6 (3058)
Brierly Brook at Braemore Ave. Bridge (B-4)	103	21.7 (768)	48.5 (1712)	Not Available	27.2 (959)	67.1 (2371)	Not Available
Brierly Brook at West River Confluence	104	24.2 (854)	50.3 (1778)	71.9 (2540)	30.4 (1072)	69.4 (2453)	99.6 (3518)

* Refer to Figure 6-1.

TABLE 27

MODEL PARAMETERS USED IN THE
PEAK FLOW SIMULATIONS FOR THE RIGHTS RIVER

Sub-Catchment Area (ID)	k (hrs)	tp (hrs)	Adjusted CN Values
301	2.2	2.8	87
302	4.2	3.7	87
303	2.1	2.4	87
304	2.4	2.4	87
305	3.5	2.3	89
306	3.6	1.8	95
307	1.6	1.6	92

The peak flows simulated for the Rights River are in fairly close agreement with those developed in the Regional Flood Frequency Analysis. The 1:20 and 1:100 year flows simulated at the mouth of the Rights River are 177 m^3/s (6252 cfs) and 246.5 m^3/s (8708 cfs), respectively as compared with 158.6 m^3/s (5600 cfs) and 216.1 m^3/s (7633 cfs), respectively in the Regional Flood Frequency Analysis.

6.6.3.1 Discussion of the Effect of the Brierly Brook Reservoir

In comparing the resulting expectation peak flows with and without the effect of the Brierly Brook Dam using the HYMO model, it can be seen that the dam has significant effect in the reduction of peak flows downstream. For the 1:20 year event, the reduction in peak flow at the outlet of the dam is approximately 67 percent and for the 1:100 year event, it is approximately 77 percent.

For the 1:20 year event, the simulated runoff volume upstream of the dam was 28.0 mm (1.10 inches). The equivalent runoff storage of the Brierly Brook Reservoir for this event was approximately 16.0 mm (0.63 inches). According to the HYMO simulations, the water level in the dam would rise to an elevation of approximately 21.8 m G.S.C. (71.5 feet).

Similarly for the 1:100 year event, the simulated runoff volume upstream of the dam was 57.2 mm (2.25 inches). The equivalent runoff storage of the Brierly Brook Reservoir for this event was approximately 25.4 mm (1.0 inches). According to the HYMO simulations, the water level in the dam would rise to an elevation of approximately 23.3 m (76.5 feet). At this elevation, the water level would be about 1.1 m (3.5 feet) below the decant outflow pipe. Unless there is some

debris blockage at the low flow outlet pipe, the dam should be able to safely store the excess runoff due to the 100-year storm.

A drawing of the Brierly Brook dam is presented in Appendix "f".

6.6.4 Upper 95% Confidence Limit Flows

Brierly Brook

In view of the lack of rainfall intensity data in the Antigonish area, it was found necessary to investigate the flows resulting from the Brierly Brook reservoir due to the upper 95% confidence limit Truro rainfall. Based on 20 years of rainfall data from the Truro station and using the Gumbel distribution, it was determined that the 6-hour upper 95% confidence limit rainfall totals for the 20 and 100-year recurrence intervals were 83.5 mm (3.29 in) and and 111.8 mm (4.40 in) respectively. These rainfall totals were distributed in time using the 6-hour AES distribution and put into the calibrated HYMO model for the Brierly Brook watershed. The simulated peak flows at various locations, with the effect of the Brierly Brook dam, are presented in Table 28. As can be seen from an analysis of Tables 26 and 28, the peak flows resulting from the upper 95% confidence limit rainfall are not significantly higher than the expectation peak flows.

Reports indicate the low level outlet of Brierly Brook dam has been partially blocked by debris and ice. In order to assess the effect on reservoir elevation of such obstructions, simulation runs by computer were made, assuming total

TABLE 28

SUMMARY OF PEAK FLOWS FOR BRIERLY BROOK
RESULTING FROM UPPER 95% CONFIDENCE LIMIT RAINFALL

Location	Flow Point Number *	1:20 Year Instantaneous Peak Flow m^3/s (cfs)				1:100 Year Instantaneous Peak Flow m^3/s (cfs)			
		Simulated with Existing Brierly Brook Dam		Simulated with Brierly Brook Dam Low Flow Outlet Totally Blocked		Simulated with Existing Brierly Brook Dam		Simulated with Brierly Brook Dam Low Flow Outlet Totally Blocked	
Inflow to Brierly Brook Dam	102	51.3	(1812)	51.3	(1812)	75.7	(2675)	75.7	(2675)
Brierly Brook at Braemore Ave. Bridge	103	25.7	(909)	15.8	(557)	33.8	(1193)	38.1	(1346)
Brierly Brook at West River Confluence	104	28.7	(1015)	18.8	(663)	37.9	(1337)	39.5	(1394)

blockage to assess the effect on water elevations and the potential for overtopping of the dam. The combination of total blockage and upper 95% confidence limit rainfall for six hours duration produce the conditions most likely to give high levels. With these assumptions no discharge can take place until the reservoir level reaches elevation 24.4 m G.S.C. (80 feet). Peak flows with and without the low outlet blocked are given in Table 28 for 1:20 year and 1:100 year conditions.

Based on the simulation results, the 1:100 year storm event would produce peak levels in the Brierly Brook reservoir to elevation 24.8 m (81.4 feet) if the low flow outlet is not blocked and to elevation 25.2 m (82.7 feet) if the outlet is totally blocked. The 1:20 year storm would produce peak reservoir levels to elevation 24.5 m (80.4) for both the open and blocked off conditions. According to the dam drawing presented in Appendix "f", the maximum permissible water level in this reservoir is 26.5 m (87.0 feet). Based on the above results, the dam should not be overtopped from the flows produced by the 1:20 and 1:100 year, upper 95% confidence limit rainfall events. Nevertheless a regular inspection program should be maintained in the event that storms in excess of 100 year recurrence interval occur in the area.

Rights River

Simulation runs with the upper 95% confidence limit rainfall for the Rights River were not undertaken since the peak flows determined in the RFFA and presented in Table 17 will be used for the hydraulic analysis.

6.7 Flow Estimates for Hurricane Beth

Brierly Brook

The peak flow produced by Hurricane Beth has been tagged locally as a 1:50 year event. Previous estimates of the peak flow range from 104.8 to 124.6 m^3/s (3700 to 4400 cfs) (Ref. 18) at the College Street bridge on Brierly Brook.

The calibrated HYMO model, without the effect of the Brierly Brook reservoir, was used to evaluate the peak flow for Brierly Brook arising from Hurricane Beth. Hourly rainfall data were obtained from A.E.S. for the Copper Lake station and were put into the HYMO model at 15 minute intervals. Approximately 261 mm (10.27 in.) of rain were recorded at this station during a 43 hour period beginning on 15 August 1971 at 4 AM E.S.T.

Prior to the occurrence of Hurricane Beth, the soil moisture conditions in the Antigonish area were quite dry as there had not been any rain in the previous ten days. This is reflected by the CN value which was computed to be 61 for the South River watershed. The simulated peak flow for Hurricane Beth at the mouth of Brierly Brook and the unit rate of runoff are presented in Table 29, together with similar data observed for adjacent watersheds.

An independent approach using the Brierly Brook hydraulic model was also utilized to verify the results obtained. The results are shown in Figure 7-2. With the use of the hydraulic model a flow of approximately 75 m^3/s (2650 cfs) seems to produce a fairly good fit with the observed high

TABLE 29

PEAK DISCHARGES AND PEAK UNIT RATES OF RUNOFF FOR VARIOUS WATERSHEDS DURING HURRICANE BETH

Hydrometric Station	Drainage Area km^2 (mi^2)	Channel Slope* (%)	Peak Discharge m^3/s (cfs)	Unit Rate of Runoff $m^3/sec\text{-}km^2$ (cfs/mi^2)
South River at St. Andrews	177.4 (68.5)	0.214	278 (9819)	1.54 (138.5)
East St. Mary's River at Newton	282 (109)	0.25	544 (19214)	1.91 (171.6)
St. Mary's River at Stillwater	1355 (523)	0.18	1280 (45210)	0.75 (67.1)
Brierly Brook at confluence with the West River	33.2 (12.4)	0.18**	69.4 (2450)***	2.1 (197.6)
Rights River at Mouth	129.2 (49.4)	0.14**	241 (8501)***	1.86 (172.1)

* Channel slopes obtained from Regional Flood Frequency Analysis

** Section 2.0 of this Report

***Simulated Peak Discharges.

water levels. The calibration of the Brierly Brook hydraulic model will be dealt with in more detail in Chapter 7.0

The unit rate of runoff obtained for the Brierly Brook watershed seems to be consistent with rates of runoff obtained from other nearby watersheds. A comparison of the various unit rates of runoff is presented in Table 29. The higher rates for Brierly Brook are to be expected due to its smaller drainage area.

Rights River

The peak flow arising from the occurrence of Hurricane Beth was also modelled for the Rights River watershed. The simulated peak flow at the mouth of the Rights River and the unit rate of runoff are shown in Table 29.

The hydraulic model for the Rights River was also used to verify the above peak flow. Based on the observed high water levels, the simulated peak flow produced fairly good results, as shown in Figure 7-3.

6.7.1 Hurricane Beth Recurrence Interval

Using the 1:20 and 1:100 year simulated expectation peak flows for Brierly Brook, the estimated recurrence interval for Hurricane Beth was determined to be between 1:100 and 1:150 year. Simularly, the estimated recurrence interval for Hurricane Beth on the Rights River was determined to be greater than 1:100 year.

In accord with the terms of reference the return period for Hurricane Beth was initially determined based on the single

station flood frequency analyses presented in the RFFA report and the observed peak instantaneous discharges on adjacent watersheds during Hurricane Beth in 1971. Based on this analysis, it was found that the return period for Hurricane Beth for South River at St. Andrews, St. Mary's at Stillwater and East St. Mary's River at Newton ranged from 1:15 to 1:50 year, as presented in Table 30. However, as indicated in this table, the number of years of record for the peak flow (Qp) is between 13 to 21 years. Given the high flows generated by Hurricane Beth in the Antigonish area and the rather short period of Qp record, the single station flood frequency analysis which includes this severe event would tend to distort the results. It is felt, therefore, that the use of the RFFA for the three hydrometric stations presented in Table 30 would be more appropriate in this situation. Consequently, the RFFA was used to establish $(Qp)_2$, $(Qp)_{20}$ and $(Qp)_{100}$. Based on the results presented in Table 30 for the RFFA, Hurricane Beth had a return period much greater than 1:100 year. Consequently, the return periods established for Hurricane Beth by simulation for both Brierly Brook and Rights River do not appear to be more severe than the adjacent watersheds. Furthermore, there is a close agreement between the flows derived using the HYMO model for the Rights River and those derived in the RFFA. These results seem to indicate that the simulated peak flows for Brierly Brook and Rights River are consistent with those observed on adjacent watersheds.

6.8 Ice Break-up Hydrology

Meteorological conditions and streamflow summaries for the Antigonish region were examined for the years in which significant flooding from ice jams had been reported. Although

TABLE 30

RETURN PERIOD FOR HURRICANE BETH BASED ON
SINGLE STATION AND REGIONAL FLOOD FREQUENCY ANALYSIS

Station Name	No. of Years of Record (Qp)*	Drainage Area (Km^2)	Frequency Analysis	$(Qp)_2$ m^3/s	$(Qp)_{20}$ m^3/s	$(Qp)_{100}$ m^3/s	Hurricane Beth Peak Flows (m^3/s)	Hurricane Beth Recurrence Interval (Years)
South River at St. Andrews	13	177.4	Single Station	80	380	880	278	15
			RFFA	92.3	188.3	260.6	278	>100
St. Mary's River at Still-water	21	1355	Single Station	481.8	1031.8	1437	1280	50
			RFFA	422.1	781.7	1053.7	1280	200
East St. Mary's River at Newton	13	282	Single Station	150	450	750	544	40
			RFFA	121.9	252.9	351.5	544	>200

* Period of record used in RFFA report

background information on the floods of 1883 and 1906 is very limited; precipitation, streamflow and air temperature data are reasonably complete from 1918 to the present.

Table 31 summarizes the results of an overview of several meteorological parameters which were present during break-up and ice jamming on the brooks and rivers around Antigonish. In general, ice jams have occurred during warm spells accompanied by rain and in those years when early-winter temperatures are colder than average. More specifically, most ice jams of interest were accompanied by:

(i) a minimum of 27 mm of rain within 24 hours (average of 35 mm or more) leading to a rapid increase in streamflow

(ii) several days of above freezing temperatures

(iii) unusually cold Decembers (an average of 190 freezing degree days during ice jam years vs long-term average of 119 freezing degree days in December) and colder than average Januarys

(iv) a minimum of about 225 freezing degree days (C°) prior to the incident

(v) ice thickness growth to a minimum of about 28 cm

It is appropriate to note, however, that ice jamming will not necessarily occur even when all of these factors combine. In February 1972, for example, all factors including 56 mm of rainfall runoff did not result in an ice jam. Similarly, a major exception to this generalization and testimony to the

unpredictability of ice jams, is the ice jam of February 1982, which was initiated by only 11 mm of rainfall and was accompanied by very little snow melt.

One parameter of particular interest in estimating the extent and frequency of flooding from ice jams is the magnitude of streamflow over the duration of the ice jam (as compared to that which may have contributed to initiating the jam) and the relative frequency of this flow. The principal factor causing streamflow at break-up appears to be a sudden input of rainfall runoff during a warm spell. Although it would be anticipated from Table 31 that the runoff from 11 mm of rainfall could trigger an ice jam, it is apparent that the runoff of about 30 mm of rainfall (or more) in the winter months could occur to contribute to flooding during ice jam events in Antigonish.

Streamflow response to winter rainfall of this magnitude is known for an extended period on the South River at St. Andrews station. Figure 6.8 gives a frequency plot of the mean daily streamflow corresponding to such events from January to early April for the period from 1917 to 1980. For the period 1933 to 1965, when this station was inactive, flow records from adjacent hydrometric stations were used. The plotted values represent the annual winter peak flow occasions when ice would be present (i.e. when several major rainfall-runoff events closely followed one another, only the first event entered the analysis. Second events, even though higher, were discarded if ice was not considered to be present).

It is concluded from this analysis, that ice jams have occurred under a wide range of flows and that the ice jams and

TABLE 31

SUMMARY OF METEOROLOGICAL CONDITIONS
PRIOR TO HISTORICAL ICE JAMS - ANTIGONISH

Date of Jam	Freezing Degrees (°C) Days before Ice Jamming				Rainfall before Ice Jam (mm)	Temperature before Jam
	Dec.	Jan.	Feb.	Mar.		
Mar. 1883	-	-	-	-	58	-
Unknown 1906	-	-	-	-	nd	-
Mar. 11-14, 1930	175	180	181	15	28	Thawing
Jan. 10-15, 1935	253	41			27	"
Jan. 21-26, 1952	153	107			37	"
Jan. 3-18, 1956	196	48			27	"
Apr. 16-18, 1964	247	226	187	97	29	"
Feb. 13-15, 1971	191	295	112		56	"
Feb. 3-5, 1973	174	249	25		32	"
Mar. 10, 1973	-	-	173	52	31	"
Jan. 1976	133	181			32	"
Feb. 3-12, 1981	231	272	10		28[1]	"
Feb. 4-5, 1982	33	240	7		11	"
Mar. 8, 1982	-	-	194	37	29	"
Long Term Average Freezing (°C) Days per Month						
1931-60*	115	183	174	83		
1951-80**	122	202	198	104		
1931-80	119	193	186	94		

1 Includes significant snowmelt
* Truro
** Collegeville

flooding of 1956 have far exceeded any other open water flood in the town's history (Ref. 12). On the other end of the scale, the flood flows in February 1982 were quite low. This suggests that once a jam has formed on the Rights River, it will remain in place during high discharge periods when this discharge spills over the banks.

Winter unit rates of runoff for the South River watershed were found to be similar to those experienced on the Rights River watershed. This was shown based on selected events recorded on both watersheds since 1979. Based on the frequency plot shown in Figure 6-8, the 1:20 year and 1:100 year mean daily flows for the South River were selected. These flows were then pro-rated on a drainage area basis to the Rights River watershed. A peaking factor of 1.80 was then determined based on the ratio of instantaneous to mean daily flows for selected winter events on the Rights River. The instantaneous peak flows determined at the mouth of the Rights River for the 1:20 year and 1:100 year were 124.7 m^3/s (4400 cfs) and 172.1 m^3/s (6080 cfs), respectively.

The above procedure could not be used for the Brierly Brook watershed because of the effect of regulation and because it is not gauged. Consequently, the HYMO model was considered for the simulation of flows for Brierly Brook. An analysis of rainfall-and-snowmelt hydrographs was conducted for the Rights River watershed to determine the shape of a typical hydrograph. A rainfall event was then selected which represented the general shape of the rain-and-snowmelt hydrograph. With this rainfall input, the antecedent conditions in the HYMO model were varied to obtain the 1:20 and 1:100 year flow at the mouth of the Rights River.

Having obtained these flows, similar rainfall and antecedent conditions were used to simulate the 1:20 and 1:100 year flows for the Brierly Brook with the effect of the reservoir. A summary of the winter flows is presented in Table 40 in Section 7.8.1.

6.9 HYMO Model Sensitivity Testing

It was found necessary to carry out sensitivity testing of the HYMO model to determine the variation in the peak flow estimates due to variation in the estimation of the HYMO parameters. Sensitivity testing was carried out for the Brierly Brook watershed with the effect of the existing Brierly Brook dam.

Sensitivity testing was undertaken by varying one parameter while holding the others at their initially determined values. The parameters which were varied are the k, tp, manning's "n", the antecedent soil moisture conditions (CN values) and rainfall.

The results of the sensitivity testing are shown in Table 32. As can be seen, variations in the k, tp and n values do not significantly affect the peak flows. However, the peak flows are fairly sensitive to the antecedent soil moisture conditions used prior to the storm event and the rainfall input.

TABLE 32

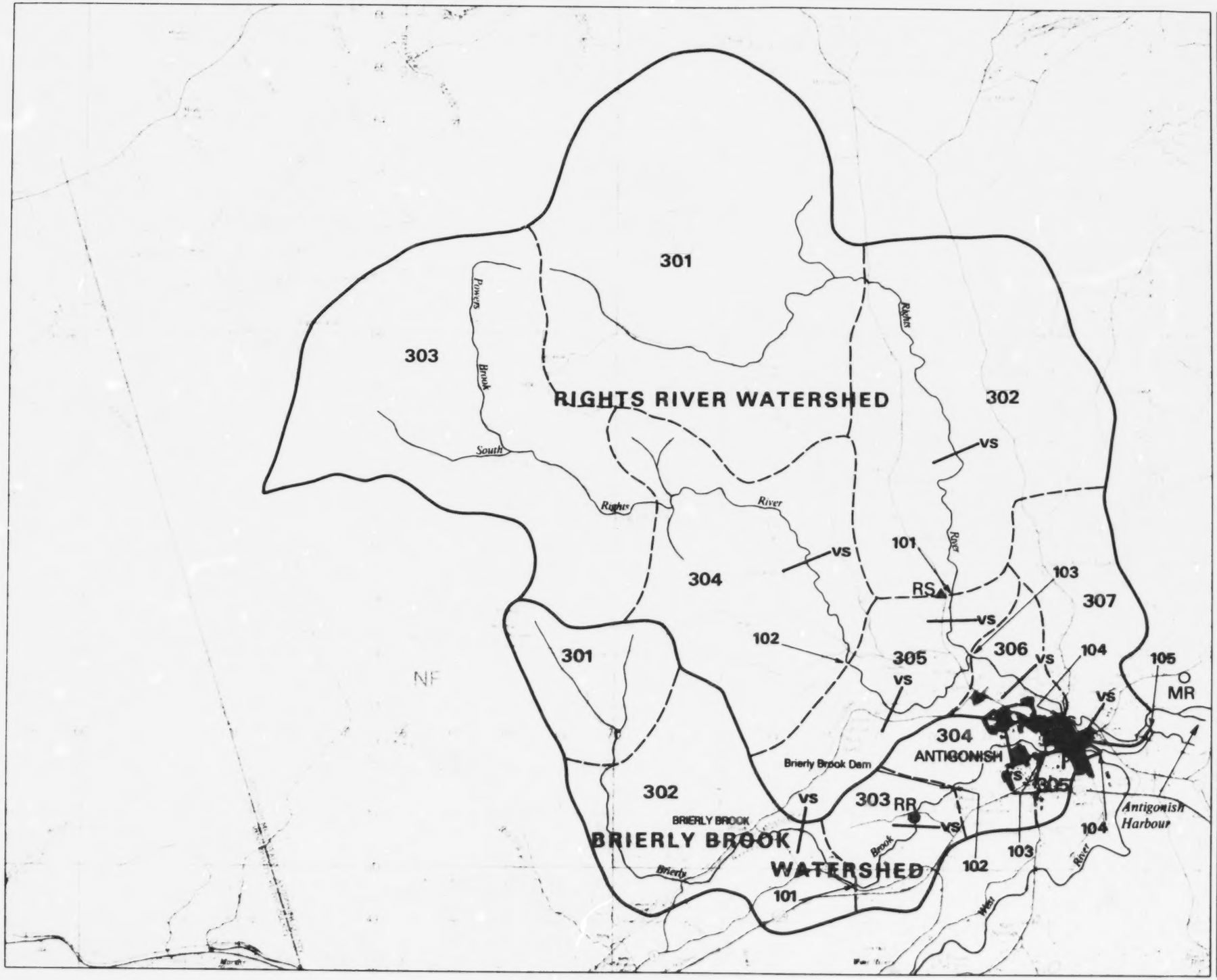
SENSITIVITY TESTING OF PARAMETERS
FOR THE BRIERLY BROOK HYMO MODEL

% Change In Parameter	Variation in Peak Flow Above the Dam (%)	Variation in Peak Flow at the mouth of Brierly Brook With Effect of Dam (%)
k +10%, -10%	-4.2%, +4.9%	-2.6, +3.2
tp +10%, -10%	-1.5%, +1.2	-0.1, +0.6
"n" +10%, -10%	-2.2%, +2.8	-1.5, +1.7
increase CN value by 5	+18.4%	+11%
decrease CN value by 5	-17.1%	-12.3%
Rainfall +25%, -25%	+36.9%, -27.8%	+24.7%, -20.3%

CANADA-NOVA SCOTIA FLOOD
DAMAGE REDUCTION PROGRAM

Figure 6-1

Rights River and Brierly Brook Watersheds



- Watershed Boundary
- Subwatershed Boundary
- 304 Subwatershed Number
- 103 Flow Point
- VS Valley Section
- ▲ RS Recording Streamflow Gauge - Rights River Near Antigonish (01DR003)
- ● RR Tipping Bucket Rain Gauge
- ○ MR Manual Rain Gauge - Antigonish Station

N

0 1 Miles

0 1 2 3 Kilometres

Figure 6-2

Calibration of Rights River Hydrologic Model
November 1981 Storm Event

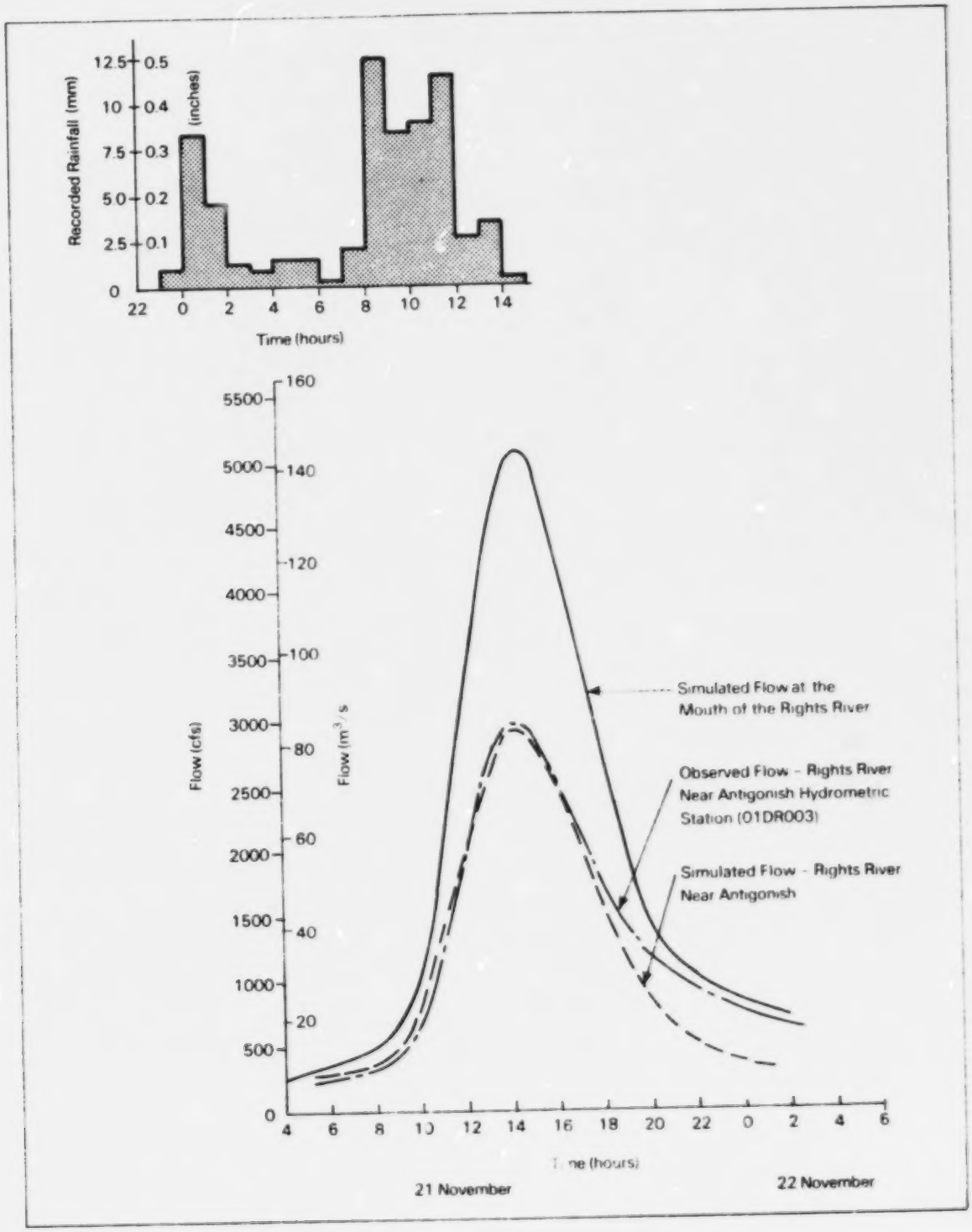


Figure 6-3

Calibration of Brierly Brook Hydrologic Model
November 1981 Storm Event

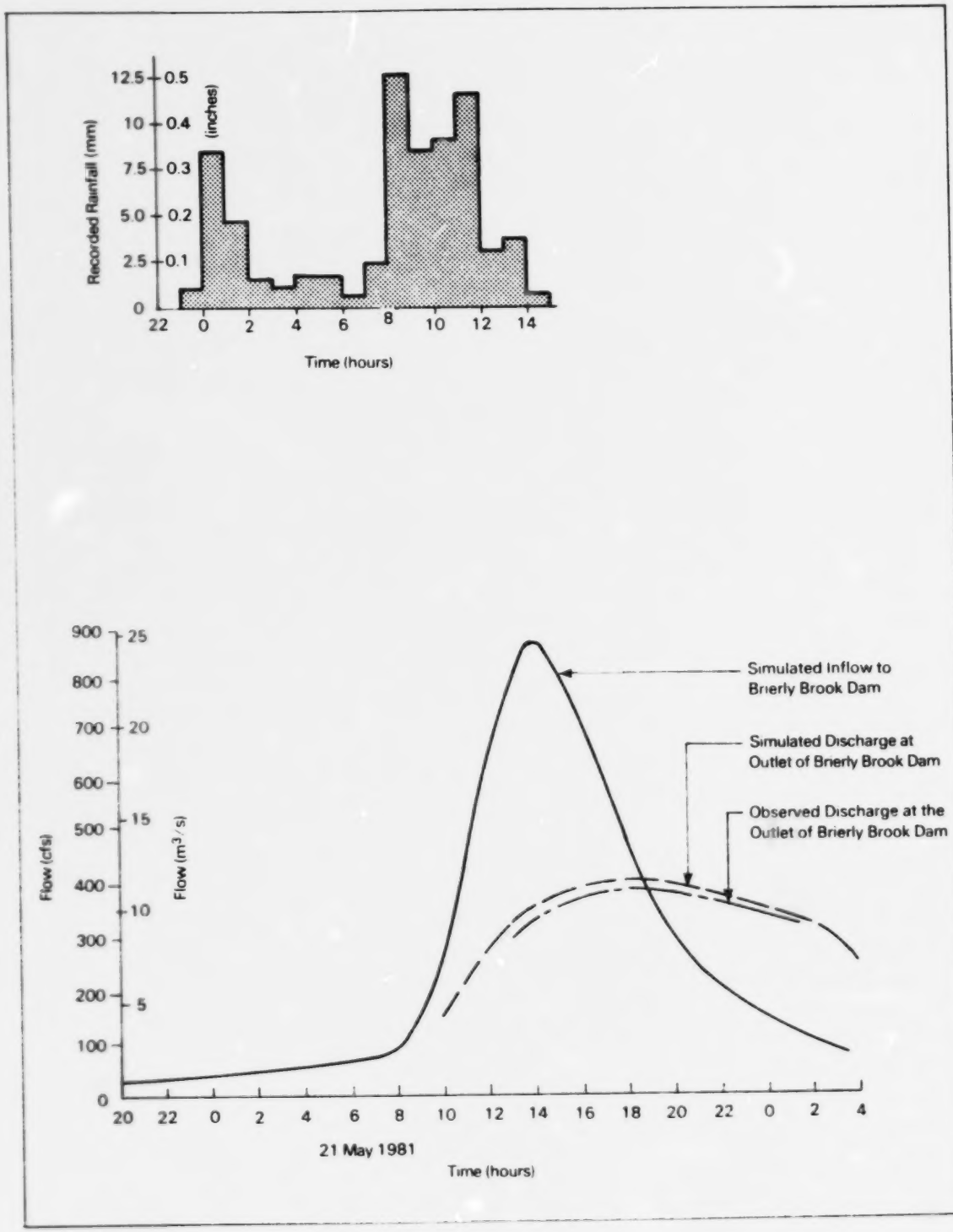


Figure 6–4

Verification of Rights River Hydrologic Model May 1981 Storm Event

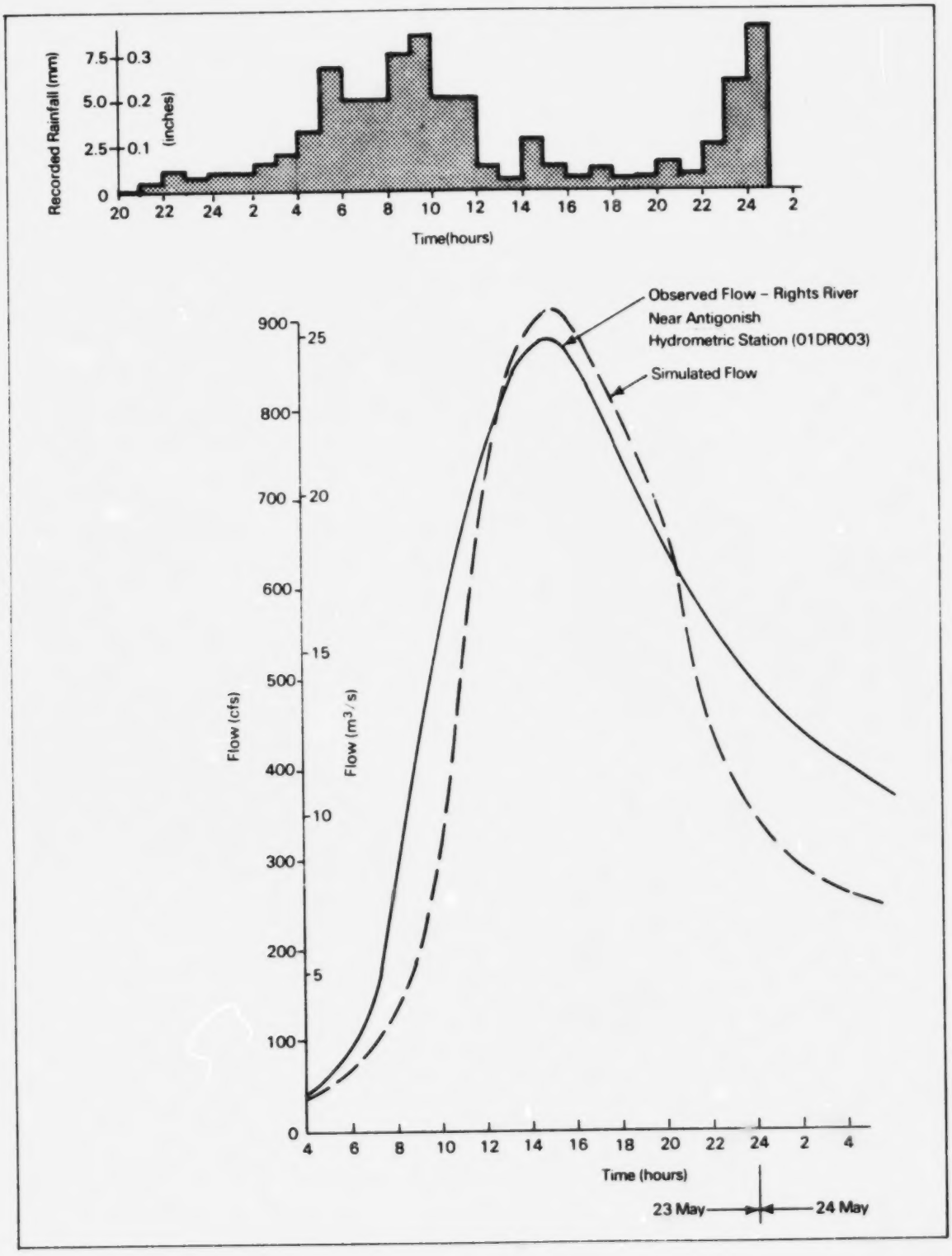


Figure 6-5

Verification of Rights River Hydrologic Model
May 1982 Storm Event

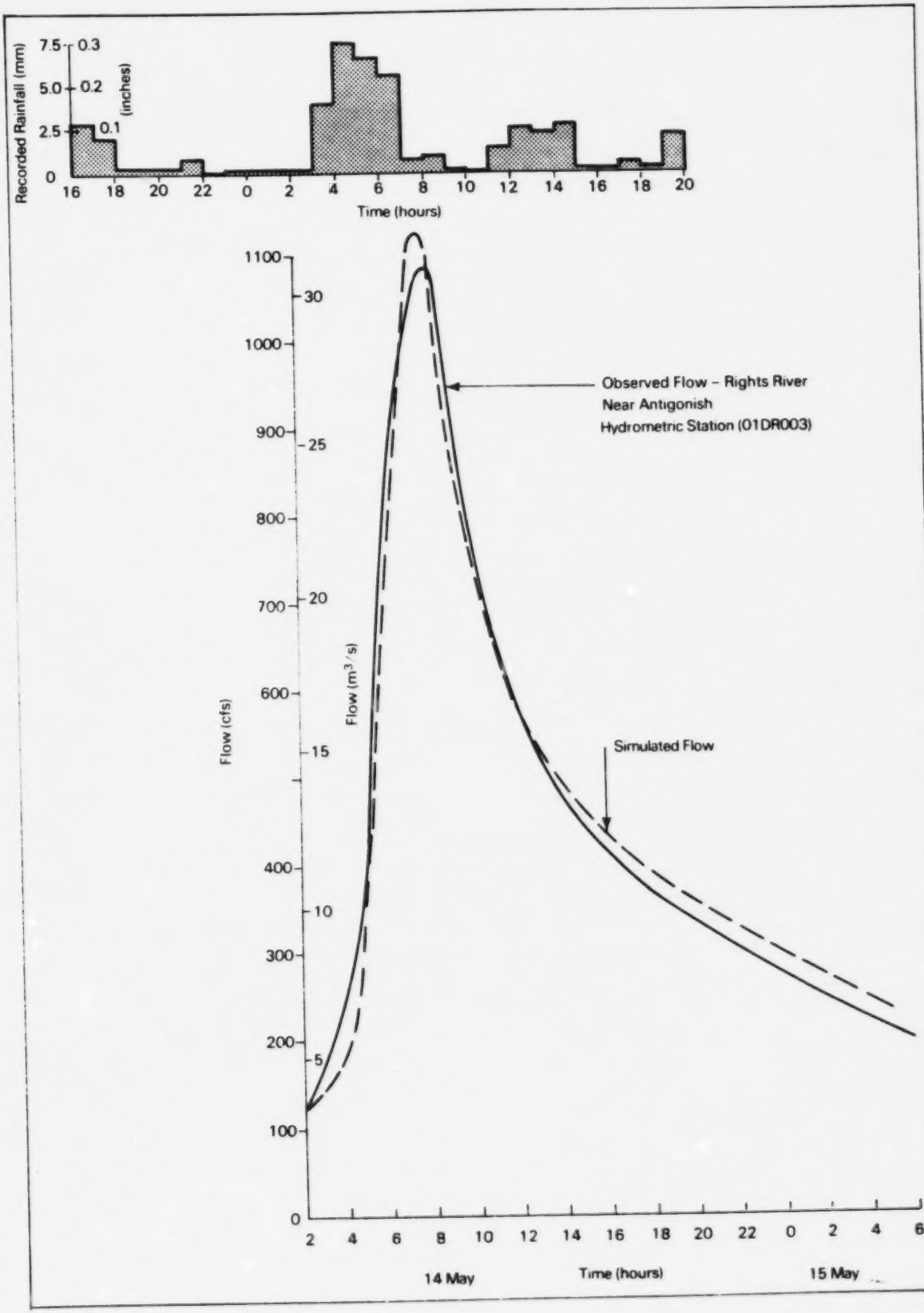
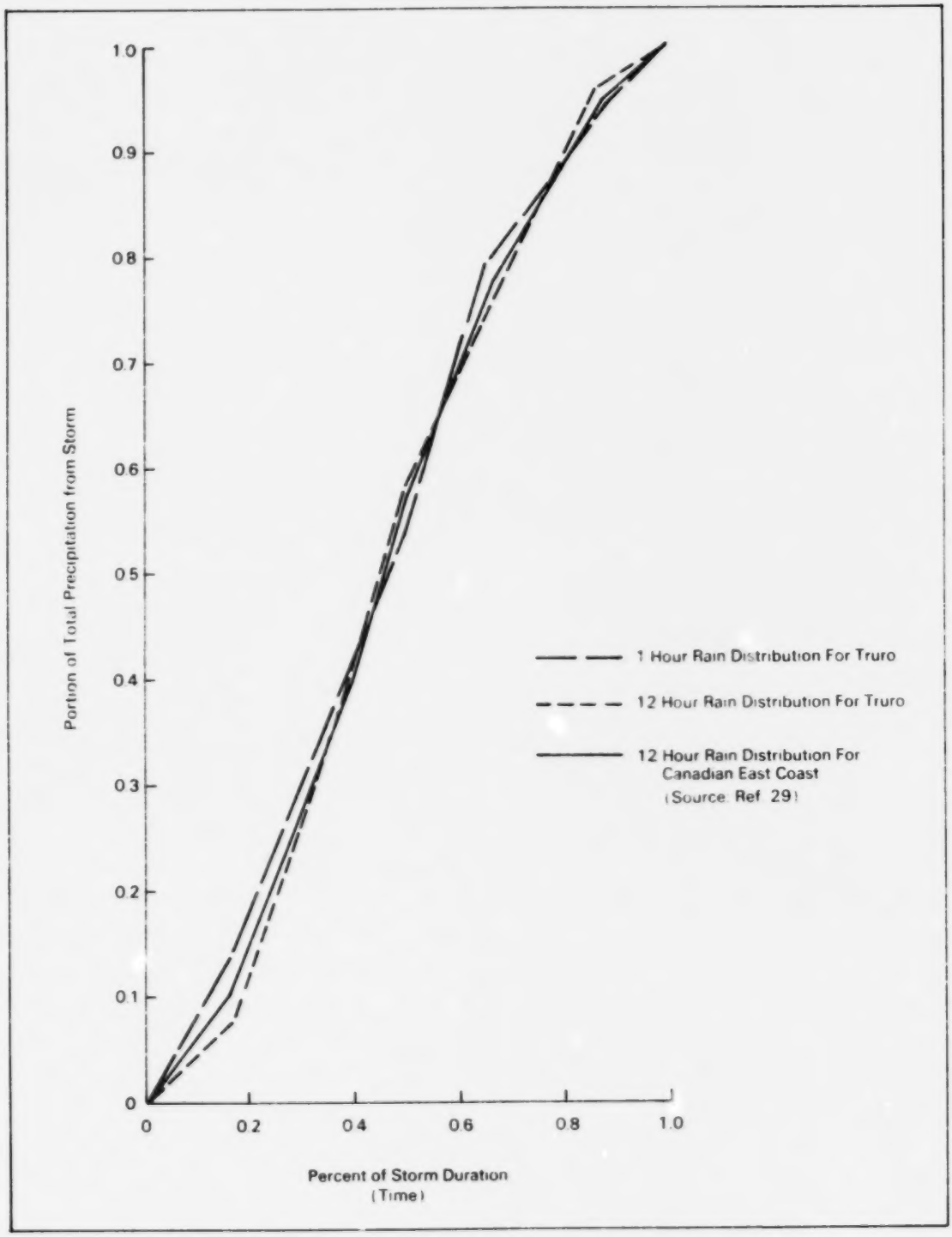


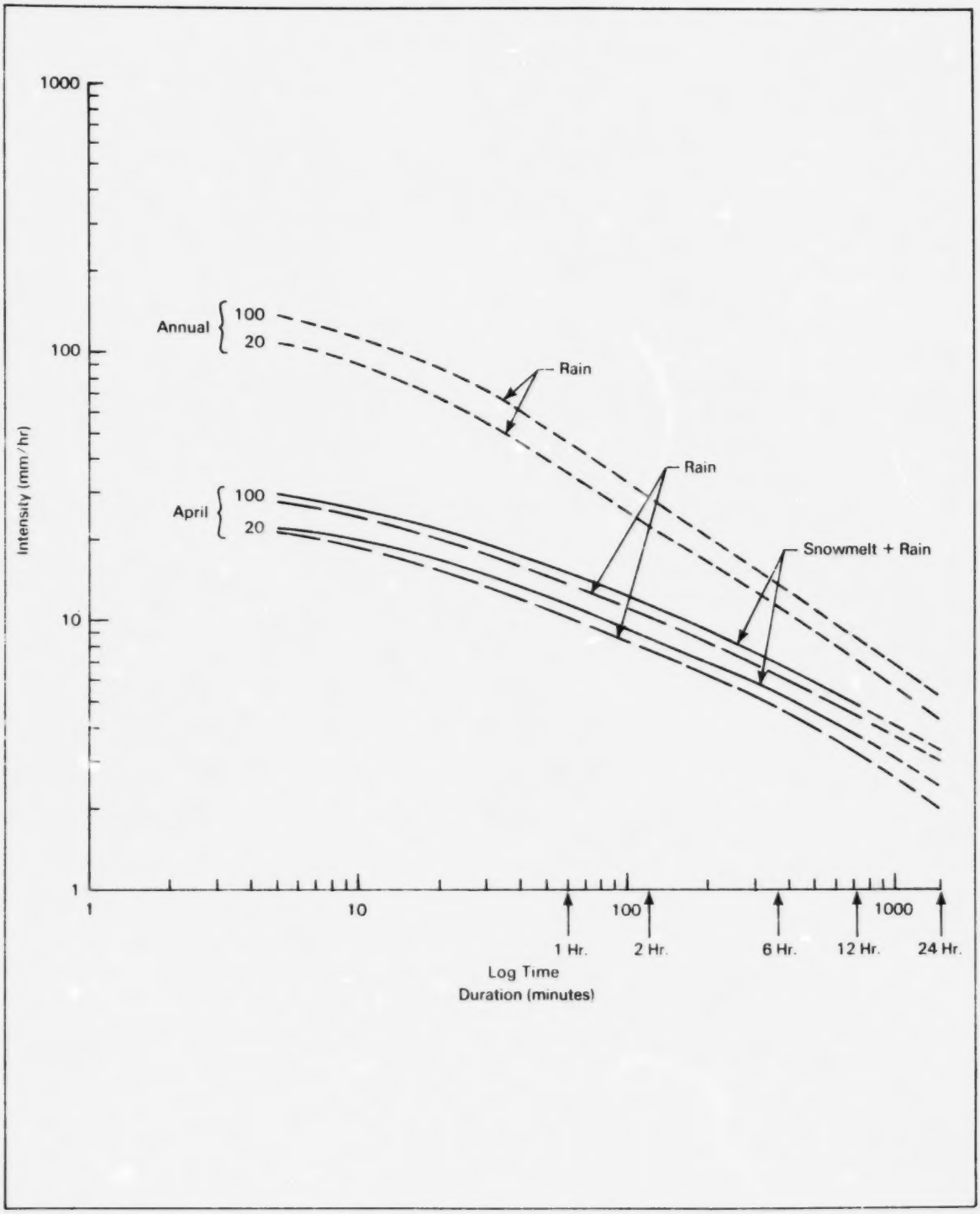
Figure 6-6

Rain Distribution in Time



01194 0

Intensity – Duration Frequency Curves For Annual and April Events Based On 1961–1979 Truro Station Record



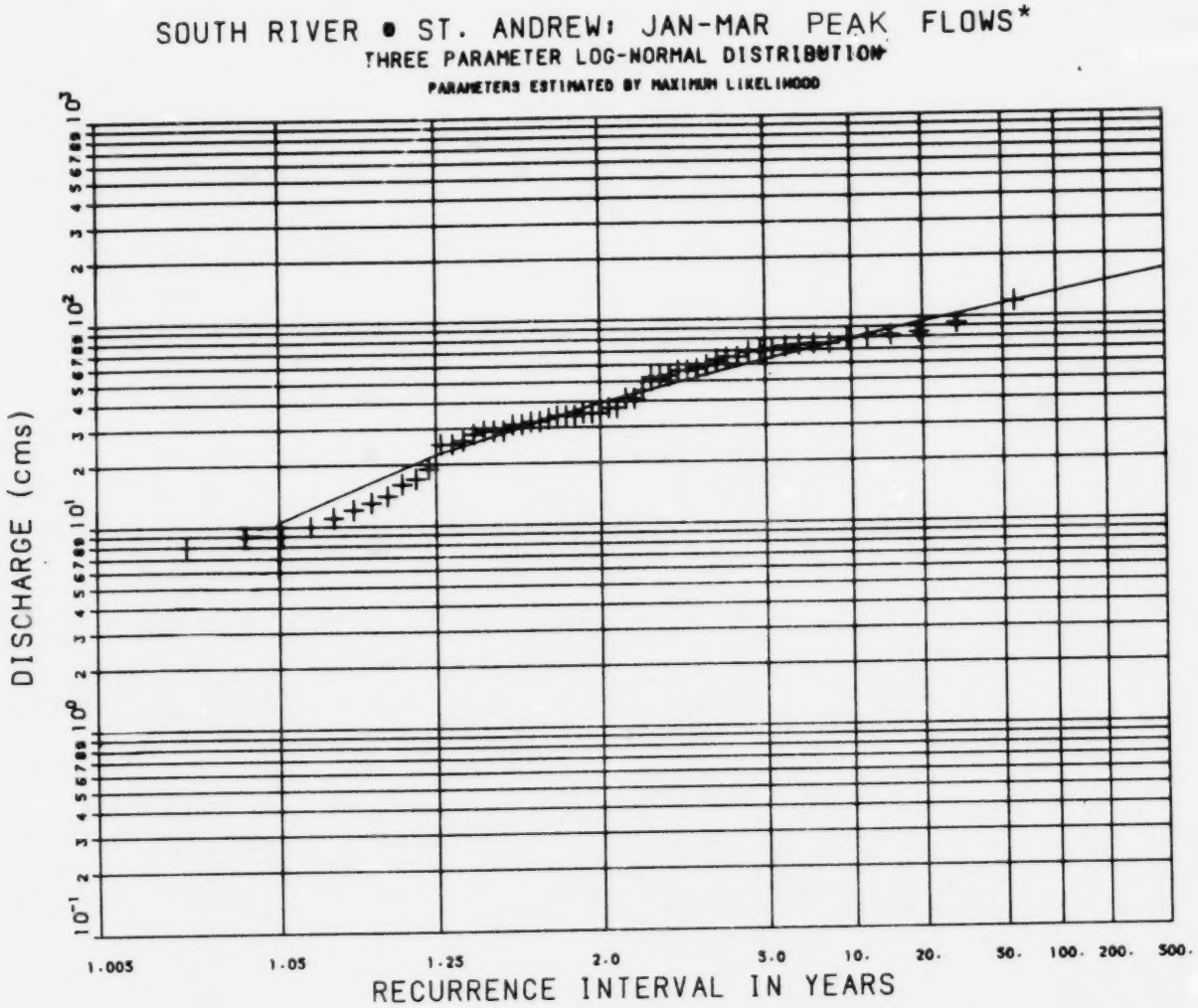


Figure 6-8

FLOOD FREQUENCY ANALYSIS
FOR ICE FLOWS FOR SOUTH RIVER
AT ST. ANDREWS

* Period of Record: 1918 - 1980

CHAPTER 7 - HYDRAULIC ANALYSIS

7.1 General Methodology

The purpose of the hydraulic investigations is to derive the 1:20 and 1:100 year water surface profiles along the study reaches. In undertaking this work, the significance of various hydraulic parameters has been investigated, including the following:

1. Channel and floodplain conveyance and storage

2. Channel constrictions at bridges and locations of floodplain infilling, etc.

3. Structures located in the floodplain.

4. The influence of tidal variations at the downstream end of the study reach.

5. The influence of ice conditions and ice jams at the various locations in the study reach on the water surface profiles.

6. The peak flows derived as described in Chapter 6.

Stage and discharge measurements were collected as part of the field monitoring program. These data were used to calibrate the backwater model for the study reach. Furthermore in order to make use of all available data, the water levels observed during Hurricane Beth were used to confirm the results obtained with the hydraulic model.

Subsequent to the model calibration and confirmation, sensitivity testing was carried out by varying model parameters. This included variations to starting water levels, peak flow rates, friction loss coefficient, and constriction and expansion coefficients. The model sensitivity testing was undertaken by changing one variable while holding the remaining variables constant during the backwater simulation and noting the changes in magnitude of the output water levels. In this manner, the relative importance of the various model parameters was determined.

7.2 Brief Description of the HEC-2 Model

The HEC-2 model was developed by the U.S. Corps of Engineers, Hydrologic Engineering Center (Ref. 22) to compute water surface profiles for gradually varied steady state flow in natural or man-made channels. The model estimates the change in water surface elevation between given river cross-sections with special computations accounting for bridge structures and other flow obstructions in the flood plain. The basic computational procedure used in the model is the solution of the one-dimensional energy equation with energy loss due to friction evaluated with Manning's equation.

Full details of the HEC-2 model and its underlying theory are given in the users manual (Ref. 22). The release used was November 1976 updated April 1980 Error Correction 04, Modification 99.4.

An HEC-2 Ice Option program has also been developed to determine the backwater levels due to ice jams. This option of the program was used to model ice jam conditions in Antigonish area streams.

7.3 Set-up of the HEC-2 Model

The location and approximate lateral extent of the cross-sections used to set up the HEC-2 model for the Rights and West Rivers and Brierly Brook are shown in Figure 7-1. As can be seen from this figure, the Rights and West Rivers were modelled as one system downstream of cross-section 1860. This is because of low-lying area between the West and Rights Rivers downstream of St. Andrews Street and because during high flows the Rights and West Rivers can both spill across Main Street, West of St. Andrews Street due to a depression in the road. Consequently, the combined flow for the two river systems was used in the hydraulic simulation downstream of cross-section 1860. Further description on the technique used to estimate the combined peak flow is presented in Section 7.7. The computed water levels at cross-section 1860 were then used as the starting water level conditions for the individual Rights and West Rivers hydraulic models.

Cross-sectional data was obtained from field surveys and from the available 1:2000 scale topographic mapping. Information on hydraulic structures across the water courses was obtained as documented in Section 5.0.

All cross-sections were coded adopting the convention of looking downstream from left to right bank. Typical cross-sections are shown in Appendix "c" along with Manning's "n" values for the channel and overbanks for Brierly Brook and the West and Rights Rivers.

7.4 Calibration of the HEC-2 Model

General

The HEC-2 model was calibrated using the high water levels observed during the November 1981 storm event. The observed Hurricane Beth high water levels were used to confirm the model results. The HEC-2 model could not be validated since other high flow storm events did not occur during the field monitoring program.

Brierly Brook

The regulated flows for the November 1981 storm were obtained as part of the calibration exercises carried out for the calibration of the Brierly Brook hydrologic model. High water levels were obtained from crest gauges installed at the College St. bridge (B-2) and the Braemore Road bridge (B-4) across Brierly Brook. A summary of the peak flows, together with observed and simulated peak water levels at various locations along Brierly Brook are presented in Table 33. The observed water levels are shown in Figure 7-2, together with the simulated water surface profile. As can be seen from this figure, there is a fairly good agreement between the observed and simulated water surface profiles.

The Manning's roughness coefficients ranged from 0.038 to 0.042 for the channel and from 0.050 to 0.055 for the over-bank area.

Rights River

The combined Rights and West Rivers model was run with a total flow of 270 m^3/s (9531 cfs) and the observed high tide level of 0.7 m (2.3 ft) in Antigonish Harbour was used as the starting water level. The resulting water level at section 1860 was then used with a flow of 142 m^3/s (5015 cfs) obtained from the HYMO output (see Section 6.4.3). This flow was then reduced to 138 m^3/s (4875 cfs) at the Cloverville Road Bridge based on the HYMO results to run the HEC-2 model for the Rights River. A summary of the peak flows, together with the observed and simulated peak water surface elevations for the Rights River are presented in Table 33. The resulting water surface profile, together with the observed water levels are presented in Figure 7-3.

West River

The HEC-2 model parameters for the West River were estimated based on the calibration results for the Rights River and Brierly Brook and from photographs taken during the field surveys. The model was then run with various flows until a good fit with the observed water levels was obtained. The peak flow that occurred during the November 1981 storm was calculated to be approximately 115 m^3/s (4060 cfs) at the Highway 104 Bridge. Although this flow seems low in comparison with the Rights River, the rainfall that occurred during the November 1981 storm was highly variable (see Section 6.4.3). It appears that the Rights River watershed experienced more rainfall than the West River and therefore a higher peak flow resulted.

TABLE 33

SUMMARY OF THE HEC-2 CALIBRATION RESULTS
FOR THE NOVEMBER 1981 STORM EVENT

Location	Cross Section Number	Peak Flow m^3/s (cfs)		Observed Peak Water Surface Elevation m (ft)		Simulated Peak Water Surface Elevation m (ft)	
Brierly Brook at Braemore Ave Bridge (B-4)	1737	16	(565)	8.30	(27.2)	8.36	(27.4)
Briefly Brook at College St. Bridge (B-2)	629	18	(636)	5.01	(16.4)	5.02	(16.5)
Rights River at CNR Bridge (R-1)	948	142	(5015)	2.0	(6.6)	1.98	(6.5)
Rights River at Cloverville Rd. Bridge (R-3)	2684	138	(4875)	5.62	(18.4)	5.61	(18.4)
West River at Highway 104 Bridge (W-3)	2969	115	(4060)	4.23	(13.9)	4.27	(14.0)

The resulting water surface profile is shown in Figure 7-4 and the observed and simulated peak water levels are presented in Table 33.

7.5 Confirmation of the HEC-2 Model Results

7.5.1 General

Due to the non-occurrence of high flow events during the field monitoring period, it was not possible to obtain peak water levels and outflows to validate the hydraulic models set-up for Brierly Brook and the Rights and West Rivers. In order to confirm as much as possible the model results, it was decided to use the high water levels observed during Hurricane Beth.

7.5.2 Confirmation Study

Brierly Brook

Before carrying out the backwater analysis for Hurricane Beth based on observed water levels, it was necessary to determine whether any bridge structures had been replaced or major modifications made to the Brierly Brook flood plain since 1971. The Nova Scotia Department of Transportation in Antigonish was contacted regarding the replacement of any bridges across Brierly Brook since 1971. The Department of Transportation stated that no bridge had been replaced or altered since that date. To determine whether major modifications had been made to the flood plain, the 1:1200 scale topographic mapping produced from the 1971 aerial photography was examined. Although more urbanization has taken place, major modifications could not be detected from comparison to the most recent 1:2000 scale topographic mapping.

Using the hydraulic model calibrated for the November 1981 storm, various runs were made to try to reproduce a water surface profile that would be consistent with the observed high water levels during Hurricane Beth. The locations of the observed high water levels for Hurricane Beth are shown in Figure 7-2. Various starting water level conditions were assumed at the outlet of Brierly Brook. It was found that the starting water level conditions did not affect the back-water conditions at a point approximately 300 metres (1000 ft) upstream of the confluence with the West River since critical depth occurs at this point. Various runs were also made for flows ranging from 70.8 to 124.6 m^3/s (2500 to 4400 cfs). Despite the number of runs made, it was found very difficult to reproduce the water level observed upstream of the Church Street Bridge. It was found that a flow of approximately 35 m^3/s (1236) cfs) would produce this water level reading upstream of Church Street. Since this flow does not appear to be a reasonable representation of the flows experienced during Hurricane Beth, this observation was dismissed as an anomaly.

A flow of approximately 75 m^3/s (2650 cfs) seems to produce a fairly good fit with the observations upstream of the College Street and Braemore bridges. There isn't a very good fit upstream of the Main Street Bridge, but the higher water levels observed could have been caused by debris blockage.

It is difficult to state with certainty the exact magnitude of the peak flow experienced during Hurricane Beth. Based on the backwater analyses carried out, a reasonable estimate of the Hurriance Beth peak flow would appear to range from 75 to 90 m^3/s (2650 to 3180 cfs).

A summary of observed and simulated peak water levels for Brierly Brook during Hurricane Beth is presented in Table 34.

Rights River

The peak flows for various locations along the Rights River were simulated for Hurricane Beth as described in Section 6.7. The overbank roughness coefficients were estimated from photographs taken during the field survey. Using the calibrated HEC-2 model for the Rights River with a flow of 241 m^3/s (8512 cfs) from the HYMO output (see Table 29), the water surface profile shown in Figure 7-3 was obtained. The hydraulic simulations were conducted with the new Rights River channel in place, that is, the post realignment and straightening of the channel near Cloverville Road. This was done in an effort to determine the flood levels should Hurricane Beth occur under existing conditions.

A summary of observed and simulated peak water levels for the Rights River during Hurricane Beth is presented in Table 34.

West River

Similarly, the calibrated HEC-2 model for the West River was used to obtain the water surface profile for Hurricane Beth shown in Figure 7-4. The model was run under various flow conditions to obtain the water surface profile that was consistent with the observed high water levels. A flow of 525 m^3/s (18 540 cfs) produced the profile shown.

A summary of observed and simulated peak water levels for the West River during Hurricane Beth is presented in Table 34.

TABLE 34

SUMMARY OF OBSERVED AND SIMULATED
PEAK WATER SURFACE ELEVATIONS FOR HURRICANE BETH

Watercourse	Cross Section Number	Observed Peak Water Surface Elevation m (ft)		Simulated Peak Water Surface Elevation m (ft)	
Rights River	922	2.44	(8.00)	2.48	(8.13)
	1728	4.54	(14.90)	4.53	(14.89)
West River	1668	4.42	(14.50)	4.77	(15.65)
	2063	4.82	(15.80)	4.69	(15.39)
Brierly Brook	379	4.51	(14.80)	5.16	(16.93)*
	720	6.74	(22.10)	6.70	(21.98)
	939	7.84	(25.70)	7.39	(24.25)*
	2028	11.06	(36.30)	11.12	(36.48)

*Refer to Section 7.5.2 for explanation

During the time that Hurricane Beth occurred, a bridge with piers was in existence at St. Andrews Street (W-2) across the West River. That bridge was replaced in 1976. The water surface profiles presented in Figure 7-4 show the backwater effects due to the old and new bridge.

7.6 Design Considerations

7.6.1 Tide Levels

As indicated in Section 4.1, continuous tide levels are measured at Pictou Harbour but not at Antigonish Harbour. According to the Canadian Tide and Current Tables, Pictou Harbour is considered a Reference Port and Antigonish Harbour a Secondary Port. The former is a port where continous tidal measurements are taken and the latter is one where in most cases the period of observation does not tend over one month and may be less. Tidal elevations and time differences are published in the Canadian Tide and Current Tables to relate the predicted tide levels at the Reference Port to a particular Secondary Port experiencing similar tidal influences.

According to these tables, at higher high water the predicted tide levels at Antigonish would be lower than those predicted for Pictou Harbour by 0.30 m (1 ft) during mean tide and 0.46 m (1.5 ft) during large tide. Similarly during lower low water the mean tide and large tide at Antigonish are lower by 0.06 m (0.2 ft) and 0.09 m (0.3 ft), respectively than those predicted at Pictou Harbour.

Tide levels are influenced by meteorological conditions such as barometric pressure and wind direction and speed. Since

these conditions could prevail during a high flow event, observed annual maximum instantaneous tide levels were obtained for Pictou Harbour to estimate the difference between the predicted and observed tide levels. A summary of the observed and predicted annual maximum instantaneous tide levels at Pictou Harbour is presented in Table 35 for the 1966 to 1979 period of record. As indicated on this table, the observed maximum instantaneous tide level for Pictou Harbour was 2.12 m (6.96 ft) G.S.C. on 20 January 1973.

Using the tidal differences established between Pictou and Antigonish Harbours for large tide during higher high water, it was possible to compute the predicted annual maximum instantaneous tide levels for Antigonish Harbour. The differences between the observed and predicted levels at Pictou Harbour shown in Table 35 were then added to the predicted tide level at Antigonish Harbour to obtain what the "observed" instantaneous tide levels would have likely been at Antigonish. This result is also presented in Table 35.

In an effort to determine the effect tide levels would have on flood elevations within the lower reaches of the study area, backwater simulations were undertaken using the HEC-2 model. Based on the results presented in Table 35, water levels of 1.0 m (3.28 ft), 1.7 m (5.58 ft) and 2.5 m (8.2 ft) were used as the various starting conditions. The 100 year, upper 95% confidence limit flow for both the Rights and West River was used for the various starting water level conditions identified above. The results of the simulations are presented in Table 36. As can be seen from this table, the starting water level conditions do not have a significant effect on flood elevations upstream of cross-section 1388. Consequently tides appear to influence flood elevations only in the lower reaches of the study area.

TABLE 35

SUMMARY OF THE OBSERVED AND PREDICTED ANNUAL MAXIMUM INSTANTANEOUS TIDE LEVELS

Year	Occurence	Observed Annual Maximum Instantaneous Tide Levels at Pictou Harbour m (G.S.C.)	Predicted Instantaneous Tide Levels at Pictou Harbour m (G.S.C.)	Difference Between Observed and Predicted at Pictou Harbour m	Computed Instantaneous Tide Levels at Antigonish Harbour m (G.S.C)
1966	Jan. 9	1.77	0.69	1.08	1.31
1967	Feb. 3	1.40	0.79	0.61	0.94
1968	Dec. 8	1.95	0.57	1.38	1.49
1969	Dec. 23	1.41	0.45	0.95	0.94
1970	Dec. 7	1.73	0.79	0.94	1.27
1971	Jan. 31	1.51	0.69	0.85	1.08
1972	Nov. 3	1.71	0.69	1.02	1.25
1973	Jan. 20	2.12*	1.11	1.09	1.74
1974	Oct. 20	1.83	0.72	1.11	1.37
1975	Oct. 7	1.70	0.94	0.76	1.22
1976	Mar. 17	1.73	0.88	0.85	1.31
1977	Dec. 7	1.91	0.88	1.03	1.45
1978	Dec. 12	1.22	0.68	0.54	0.76
1979	Feb. 13	1.32	0.88	0.44	0.86

*Extreme during period of record

Source: Marine Environmental Data Service, Fisheries and Marine Services, Environment Canada.

TABLE 36

SIMULATED WATER SURFACE ELEVATIONS AT THE LOWER REACHES OF THE WEST AND RIGHTS RIVERS UNDER VARIOUS STARTING WATER LEVEL CONDITIONS

Cross Section* Number	100 Year, +95% Confidence Limit Flow (m^3/s)	Water Surface Elevation (m)	Water Surface Elevation (m)	Water Surface Elevation (m)
0	1005.	1.00	1.70	2.50
200	1005.	2.10	2.10	2.59
600	1005.	2.59	2.59	2.82
850	1005.	2.83	2.83	2.99
922	1005.	3.89	2.89	3.03
948	1005.	3.14	3.14	3.23
1008	1005.	3.22	3.22	3.30
1088	1005.	3.32	3.32	3.39
1208	1005.	3.56	3.56	3.61
1388	1005.	3.78	3.78	3.82

*Refer to Figure 7-1

A frequency analysis was also carried out based on the observed tide levels presented in Table 35 for Antigonish Harbour. Based on this analysis, it was estimated that the 2 year tide level is 1.17 m (3.84 ft), 20 year is 1.80 m (5.91 ft) and 100 year is 2.19 m (7.19 ft).

7.6.2 Design Criteria

In Chapter 6, it was established that Hurricane Beth had a recurrence interval in excess of 100 years for both Brierly Brook and the Rights River. In Section 7.8 of this chapter, it is also indicated that elevations due to ice jams are substantially higher than the flood elevations arising from the 20 and 100 year expectation flows. On this basis, it was decided to adopt the 1:20 and 1:100 year upper 95% confidence limit flows.

The criteria presented below were used to determine the governing 1:20 and 1:100 year water surface profiles at the lower reaches of the study area where the Rights River and West Rivers empty into the Antigonish Harbour. This criteria gives a conservative approximation of the joint probability of the 1:20 and 1:100 year flood levels arising from a combination of stream flow and high estuarine levels.

100 Year Water Surface Profile

Governing water surface profile will be the greater of:

100 year, +95% confidence limit flow with 2 year tide level

or

2 year, +95% confidence limit flow with 100 year tide level

20 Year Water Surface Profile

Governing water surface profile will be the greater of:

20 year, +95% confidence limit flow with 2 year tide level

or

2 year, +95% confidence limit flow with 20 year tide level

A similar procedure was also used to obtain the governing water surface profiles for the area at the confluence of Brierly Brook and West River. However, the 1:20 and 1:100 year water surface elevations resulting from the West River at the confluence with Brierly Brook were used instead of the tide levels.

7.7 Computed Open Water Flood Levels

As indicated previously, the RFFA flows were used for the West and Rights Rivers and the results of the HYMO model were used for Brierly Brook. The results of the HYMO model for the Rights River were used to pro-rate the RFFA flows to various points along the Rights River. Flows for the West River were taken directly from the RFFA report. However, as indicated in Section 7.3, the West and Rights Rivers downstream of cross-section 1860 were modelled as one system. The peak flow at the lower reaches of the West and Rights Rivers was obtained by considering the combined runoff effect from both watersheds. A peak flow of 692 m^3/s (24441 cfs) for the 1:20 year and 1005 m^3/s (35496 cfs) for the 1:100 year, upper 95% confidence limit flows, were obtained by using the regression equations from the RFFA report with the following parameters: drainage area (D.A.), 481 km^2; drainage density factor (D.F.), 0.19; mean annual runoff (MAR),

890 mm; mean snow depth at the end of March (MSM), 141.2 mm; and longitude, 61.98. For Brierly Brook it was found that for the 1:100 year, +95% confidence limit flow, the peak flows downstream of the Brierly Brook Dam were higher with the low flow outlet blocked off. However for the 1:20 year, +95% confidence limit flow, the peak flows downstream were higher with the low flow outlet open. According to the HYMO simulations, the higher peak flow results for the latter condition because the peak releases from the dam coincide with the peak flows from downstream sub-catchment areas. The peak flows used for the hydraulic simulations of the 1:20 and 1:100 year open water flood profiles are presented in Table 37.

The hydraulic modelling of the lower reaches of the West and Rights Rivers as one system with the HEC-2 model presented some special problems due to the difficulty of modelling two parallel bridges. Initially, the Main Street and the McAmis Bridges were modelled as one large bridge with two openings and one large "pier". However, this did not prove satisfactory as the results obtained did not seem reasonable. It was decided to carry out the hydraulic analysis with the HEC-2 model to the downstream face of the bridges (cross-section 1623), manually compute the head losses through the bridges and then run the HEC-2 model for the upstream cross-sections (1668 to 1860) using the manually computed water level upstream of the bridge as the starting water level conditions. Multiple runs were undertaken with the HEC-2 model to establish energy-flow relationships for the two bridges. Energy-flow relationships were also derived using weir flow equations for the appropriate sections of Main Street and St. Andrews Street. A combined energy-flow relationship was then derived for the two bridges and road sections. By subtrac-

TABLE 37

DESIGN FLOWS FOR INPUT TO THE HEC-2 MODEL

Watercourse	Cross Section Number*	20 Yr, +95% Confidence Limit Flow (m^3/s)	100 Yr, +95% Confidence Limit Flow (m^3/s)
Rights and West Rivers at Mouth	0	692	1005
West River	1388	574.9	840.2
	1893	537.1	786.1
Rights River	1388	326.7	468.9
	2702	318	456
	3515	315	451
	4772	311	446.4
	4857	151.4	217.3
	4893	291.1	417.9
Brierly Brook	20	28.7	39.5
	629	27.2	38.8
	1748	25.7	38.1
	2028	24.2	37.5
	2178	21.5	37.0
	2728	18.4	36.5
	3277	16.6	36.0
	3525	14.1	35.5

*Refer to Figure 7-1

ting the velocity heads for the 1:20 and 1:100 year flows from the appropriate energy levels, the 1:20 and 1:100 year water surface elevations were computed upstream of the bridges.

For cross-section 0 to 200 at the lower reaches of the West and Rights Rivers, backwater simulations showed that the combination of the 1:2 year, upper 95% confidence limit flow and the 1:100 year tide level produced the governing water surface profile. However, upstream of cross-section 200, the 1:100 year upper 95% confidence limit flow and the 1:2 year tide level produced the governing water surface profile. Similar results were obtained for the governing 20 year water surface profile.

For the area at the confluence of Brierly Brook with the West River, backwater simulations showed that the combination of the 1:100 year West River water surface elevation and the 1:2 year flow along Brierly Brook produced the governing water surface profile. However, upstream of cross-section 530, the 1:100 year upper 95% confidence limit flow along Brierly Brook produced the governing water surface profile. Similar results were obtained for the governing 1:20 year flood profile downstream of cross-section 379.

The computed open water flood profiles for the 1:20 year and 1:100 year, upper 95% confidence limit flows are presented in Figures 7-5 to 7-7 for each of the three streams. The water surface profiles resulting from the 1:20 and 1:100 year expectation flows are also shown. The computed water surface elevations at each cross section shown in Figure 7-1 are presented in Appendix "g" for the 1:20 and 1:100 year, upper 95% confidence limit flows.

7.8 Ice Jams

Brierly Brook

A number of physical factors may contribute to the formation of ice jams on this stream. Evidence from 1981 and 1982 ice observations suggest that small jams first form at a number of locations between the Braemore Avenue Bridge (B-4) and the West River. Usually ice in these accumulations floats downstream with rising water levels to the reach extending from above the Church Street Bridge down to the West River. At this reach, the upstream ice either adds to the severity of any accumulation which may already exist or it may initiate the formation of an ice jam.

Photographic evidence together with topographical mapping prepared for this project suggest that the small, initial, ice accumulations may form at about seven locations below Braemore Avenue (identified in Table 38). For the most part, it is only at the Church Street bridge and in the reach between this bridge and the West River, that the ice forms a significant jam. At the bridge , conveyance may be dramatically reduced by ice, which in turn, causes considerable upstream flooding and the passage of flow over Church Street (e.g. 1981). Downstream of the bridge much of the ice is held in the narrow tree-lined channel; but where openings occur, there is overbank spillage of ice and water toward the West River. For the most part, ice does not completely clear the Brierly Brook channel until breakup has occurred on the West River.

TABLE 38

BRIERLY BROOK
AREAS OF ICE ACCUMULATION

Area		Comment
1.	Confluence with the West River	Ice clearing obstructed by consolidated cover on the West River
2.	About 100 m above West River	narrows, a bar and a bend restrict the channel conveyance
3.	Below Church Street Bridge	channel is narrow and tree-lined
4.	Church Street Bridge*	shallow bar beneath the structure and limited conveyance - becomes blocked
5.	Midway between Church and College Streets	narrows, bend and shoal
6.	Between College and Main Streets	shallow bar at bend and narrows at bridges
7	Between Main Street and Braemore St. Bridges	sharp bends, shallows

* Locations where ice accumulations are known to be maintained through rising flood stages and where backwater flooding is most significant

Rights River

Break-up on the Rights River appears to be largely controlled by the ice cover between the harbour and the Main Street Bridge. It is reported that ice in this area usually remains consolidated through the CNR Bridge and into the harbour well after the rest of the river is clear. Further upstream between the CNR Bridge and the Main Street Bridge, there are a number of bars and shallows which constitute obstruction to downstream passage of ice. Above this area, there is evidence from our observations that general break-up and downstream movement may result from the break-up of small upstream jams. These appear to form temporarily at the four upstream locations outlined in Table 39. Until 1982, break-up of these small jams was reported to clear ice from the river down to the reach below the Main Street Bridge. If a jam formed, it was in the interval downstream of St. Andrews Street where floodwaters and ice usually spilled unnoticed or harmlessly on the interval lands. It appears, however, that an ice jam in this area in 1975 may have flooded part of St. Andrews Street, and that more significant ice jams in 1956 caused flooding over Main Street. It is not known whether the 1956 ice jam was located at or near the Main Street Bridge, but the flooding effects were similar to those which resulted from the jam in February 1982.

It is not known if the jam of March 1982 at the Cloverville Bridge is typical for the area because it is the first since channelization in 1972. However, as ice is reported to have struck the low chord of an earlier bridge at this location, it is possible that flooding of a similar nature may have occurred near Arbour Drive in the past.

TABLE 39

RIGHTS RIVER
AREAS OF ICE ACCUMULATION

Area		Comment
1.	CN Bridge crossing at the estuary	consolidated cover obstructs ice excursion into the harbour
2.	Between Main Street Bridge and CNR Bridge	bars, and shallows, one of which is only 60 m below Main St. Bridge (cover reportedly frozen to bed)
3.	Main Street Bridge*	shallow bar on south bank
4.	About 250 m above Main Street Bridge	large bar on west bank
5.	About 200 m below Cloverville Road Bridge	confluence of a small tributary stream
6.	About 50 m below* Cloverville Road Bridge	shallow bar and rapids spanning the channel
7.	Above Cloverville Road Bridge	islands, bends and rapid sections

* locations where ice accumulations are maintained through rising flood stages and where backwater flooding is most significant

West River

Ice jams on the West River appear to have initiated on the piers of the McAmis Bridge (W-2). The bridge has been replaced by a clear span and is no longer considered a likely site for ice jamming. Although there is practically no other information on ice jams on the West River, evidence from 1981 observations indicate that shallow areas upstream of the harbour ice may initiate jamming in the reach downstream of St. Andrews Street.

7.8.1 Ice Effect Flooding

Due to the lack of reliable ice jam information for the West River, it was not possible to carry out hydraulic analysis to assess the backwater effect due to ice jams. Consequently, these analyses will be undertaken only for the Rights River and Brierly Brook.

Tables 38 and 39 outline the key areas where ice has accumulated and resulted in damaging floods in Antigonish. These are:

1) Brierly Brook at the Church Street Bridge

2) Rights River near the Main Street Bridge

3) Rights River near the Cloverville Bridge

Ice jams in these areas appear to have been "dry" ice jams (in contact with the streambed) which cause a large and rapid rise in upstream water levels. There is only limited and qualitative information on these backwater levels in most

years, however, and a good portion of this information relates to hydraulic conditions which were present before recent channelization work, bridge replacement and street elevation changes. As a result, the ice jam conditions and levels observed in the streamflow monitoring program through the winters of 1980-81 and 1981-82 were used as the primary source of information for the following projection of flood levels resulting from ice jams.

Ice on Brierly Brook is reported to have blocked the opening of the Church Street Bridge on many occasions in the past, and it did so in February 1981. On that occasion, ice was resting on the stream bed and piled to an elevation which reached the bottom chord of the bridge. Between 60% and 90% of the opening was estimated to have been blocked by ice and Church Street was flooded at the bridge.

Although ice jams on the Rights River are less frequent than those on Brierly Brook, those in 1956 and 1982 near Main Street led to wide-spread flooding. Very little is known about ice jams prior to 1982 except that the top of past ice accumulations has been in contact (or nearly in contact) with the low chord of the Main Street Bridge, and that the solid ice cover downstream of the bridge initiated the jam. The top of the ice jam in 1982 reached to within about 0.3 m (1 foot) of the bridge and appeared to effectively block about 80% of the bridge opening. Although ice in the channel at the bridge was grounded in places, the upstream ice accumulation remained above the bed.

The 1982 ice jam at the Cloverville Road Bridge was the first since this reach was channelized and it originated at consolidated, bottom-fast ice contained in the channel downstream

of the bridge. Approximately 50% to 75% of the bridge opening became blocked and backwater levels rose to about 6.8 m (22.31 ft.) upstream of the bridge.

The type and location of previous ice jams on the West River are unknown, except that it appears they were associated with piers of the old McAmis Bridge now replaced. Although no ice jams were observed during break-up in 1980-81 and 1981-82, the large bend at Columbus field or the sharp turn upstream of McAmis Bridge stand out as possible sites for ice jamming.

The above-mentioned ice jam sites and conditions caused by ice accumulations were observed during recent ice jams, and it is considered possible that these same conditions may be present during the 1:100 year and 1:20 year winter floods. Table 40 summarizes these ice conditions and presents flood flows which were employed in the HEC-2 and HEC-2 Ice Option program to determine the backwater levels which may arise from ice floods in Antigonish.

The HEC-2 (Ice Option) program was employed to provide an estimate of the backwater levels arising from ice floods. The model is appropriate for estimating backwater levels caused by floating ice covers at some distance upstream of an ice jam site, but is not well suited for modelling water levels at the downstream end of an ice jam particularly if this jam is in contact with the river bed. As this type of jam is present in Antigonish, the configuration of the downstream channel and of the jam was simulated by adjusting bed contours and ice thickness parameters until backwater levels corresponded to known levels from the 1981 and 1982 ice jam floods. This same bed configuration was then employed to

TABLE 40

BACKWATER MODELLING FOR ICE JAM CONDITIONS IN ANTIGONISH

Jam Location	Winter Flood Flows m^3/s (cfs)	Modelling Approach and Ice Conditions Simulated
Brierly Brook at Church Street	20 year - 16.0 (565) 100 year - 19.1 (675)	90% closure of the bridge by ice with spill over Church Street
Rights River at Main Street	20 year - 122.5 (4327) 100 year - 168.9 (5966)	80% closure of the bridge by ice and an ice cover extending up to Cloverville Road
Rights River at Cloverville Road	20 year - 121.1 (4277) 100 year - 167.2 (5906)	75% closure of the bridge by ice and an ice cover extending 600 m upstream

estimate backwater conditions during design flood flows. The flood levels developed through this simulation of ice jam conditions are summarized for several example cross-sections in Table 41.

This approach for simulating ice jam flood levels appears to provide reasonable results but should only be used as a general guideline because ice jam modelling is still somewhat qualitative. It may be concluded, however, that backwater levels from ice jams on the Rights River will be higher than open water levels for the same return period but not significantly different than levels developed by the 95% confidence interval flood. On Brierly Brook, ice jam water surface elevations which have occurred since the construction of the dam have risen above the 95% open water levels between Church Street and College Street. However, as shown in Table 41, the ice jam water surface elevation at cross-section 457 is not significantly higher than the 1:100 year water levels due to the upper 95% confidence limit flow. Consequently, in order to be consistent throughout, the open water surface elevations resulting from 1:20 and 1:100 year backwater effect from the West River have been adopted for the lower part of Brierly Brook (refer to Appendix "g" for extent of backwater effect).

7.9 Sensitivity Testing for the HEC-2 Model

The HEC-2 model for the Antigonish area streams was calibrated and the results confirmed with available historical data. Engineering judgement had to be used in estimating some of the parameters in the model due to limited calibration/validation data. In order to test the sensitivity of the computed water levels to variations in parameters within the

TABLE 41

FLOOD LEVEL SUMMARY AT REPRESENTATIVE LOCATIONS IN ANTIGONISH

Location, Description and Cross-section No. (Figure 7-1)	Water Surface Elevation Estimates					
	1:20 Year Floods			1:100 Year Floods		
	Open Water	Ice Cover	95%*	Open Water	Ice Cover	95%*
Brierly Brook between Church and College (457)	4.45	5.47	4.66	4.66	5.51	5.17
Brierly Brook between College and Main (720)	5.58	5.71	5.77	5.77	5.83	6.01
Rights River above Main St. Bridge (2050)	4.31	5.40	4.57	4.57	5.80	5.16
Rights River below Cloverville Road (2450)	4.96	5.72	5.70	5.70	6.10	6.01
Rights River at Trailer Park above Cloverville Road Bridge (2762)	6.47	7.61	7.82	6.82	8.05	8.36

* Upper 95% confidence limit elevations under open water conditions.

model, a number of computer runs were made by varying one parameter while holding the others at their initially determined values.

Sensitivity testing was carried out for Brierly Brook. The parameters changed in the computer modelling were: flow, starting water level, Manning's n and the expansion/contraction coefficients. Each of the parameters above was varied by +10%, -10% while holding the other parameters fixed. The 1:100 year, upper 95% confidence level flow was used for the sensitivity testing.

The results of the testing are given in Table 42 for selected location along Brierly Brook. The approximate locations of the cross-sections are shown in Figure 7-1. As can be seen from this table, the variations in the compared water depths are fairly small for the parameter variations tested.

7.10 Profile Recommendation

Based on the results summarized in Table 41, we recommend that the water surface profiles arising from the 1:20 and 1:100 year upper 95% confidence limit flows be adopted as the design profiles for Brierly Brook and the Rights and West Rivers. The exception to this is from the confluence of the West River to cross-section 530 (1:100 year) and 379 (1:20 year) where the backwater effect from the West River governs and for cross-section 0 to 200 for the lower reaches of the West and Rights Rivers where the tide levels from Antigonish Harbour governs.

TABLE 42

SENSITIVITY TESTING FOR BRIERLY BROOK HEC-2 MODEL

% Change in Parameter	Variation in Computed Water Depths (%) at Cross-Sections Indicated*			
	457	604	720	939
Flow +10%, -10%	+2.9%, -2.9%	+5.2%, -3.9%	+4.9%, -4.3%	+4.1%, -3.5%
Starting Water Depth +10%, -10%	no change	no change	no change	no change
Manning's n +10%, -10%	+1.4%, -5.7%	+3.3, -7.8%	+3.1%, -4.3%	+1.8%, -0.6%
Expansion and Contraction Coefficients +10%, -10%	+1.8%, -2.1%	+0.65%, -1.3%	+0.6%,-0.1%	+1.2%, -0.6%

* Refer to Figure 7-1

7.11 Preparation of Flood Risk Mapping

The appropriate flood profiles were then transferred to the specially prepared 1:2000 contour mapping to delineate the 1:20 and 1:100 year flood risk mapping for the Antigonish area. These maps will be used, by others, to prepare appropriate flood risk mapping.

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Figure 7-1
Approximate Location of Cross-Sections For Input to the Hydraulic Model

1720 Distance Along Centre Line of Channel

1380 Location and Extent of Surveyed Cross-Section

Approximate Built-up Area

Town Boundary

Metres 0 500 1000

Feet 0 1000 2000 3000 4000

ROUTE 245
CLOVERVILLE ROAD
ROUTE 337
South Rights River
HAWTHORNE STREET
ARBOUR DRIVE
BROOKLAND STREET
COLLEGE STREET
ANTIGONISH
MAIN STREET
ANDREWS STREET
Rights River
Antigonish Harbour
MAMS BROOK
HIGHLAND DRIVE
MACMORE AVE
Brierly Brook
WEST STREET
ST ANDREW STREET
CHURCH STREET
SAINT FRANCIS XAVIER UNIVERSITY
ANTIGONISH MALL AREA
JAMES STREET
TRANS-CANADA HIGHWAY 104
ROUTE 4
BRIERLY BROOK DAM
SOMERS ROAD
To Truro
To Sydney
West River

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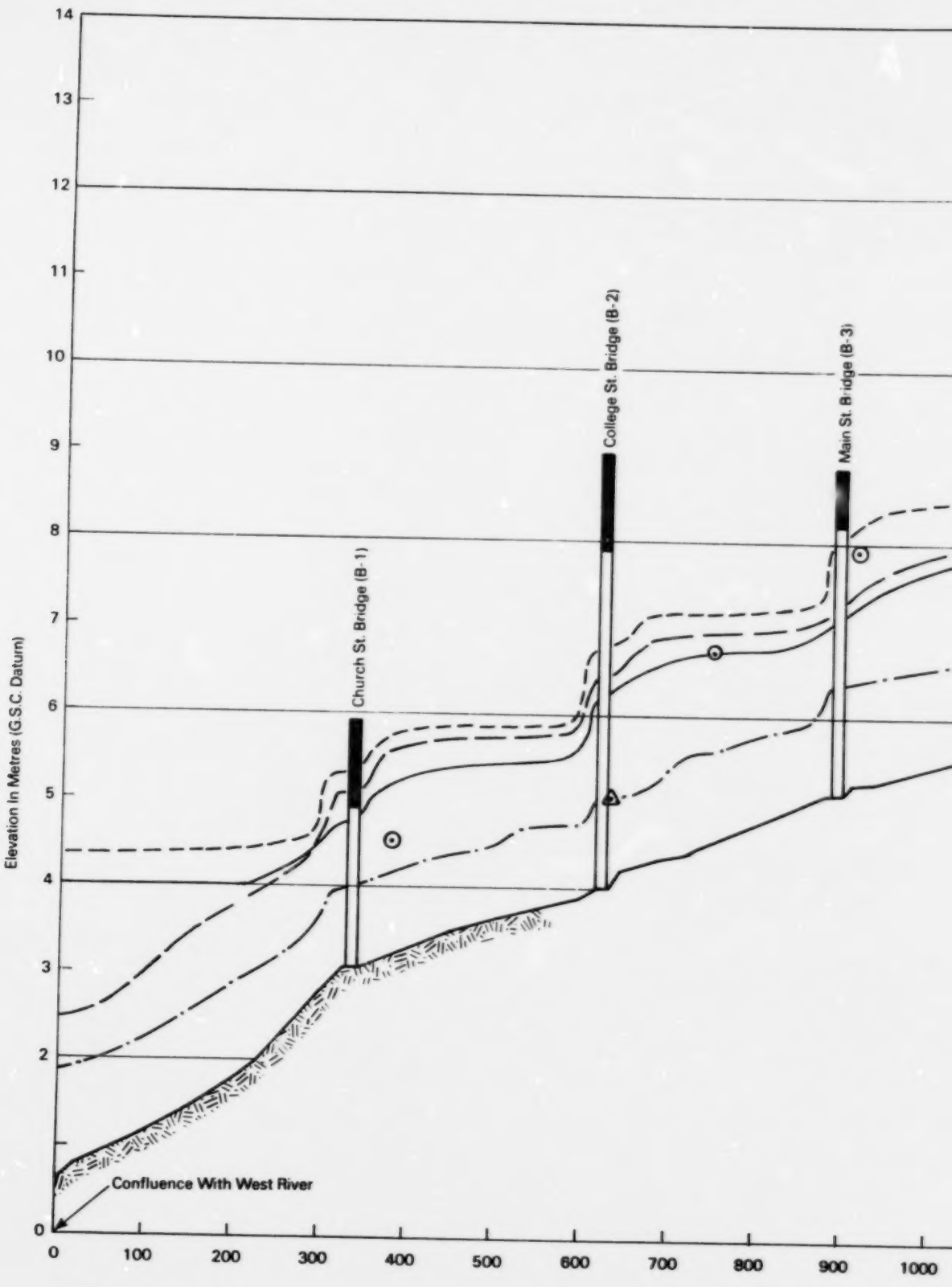

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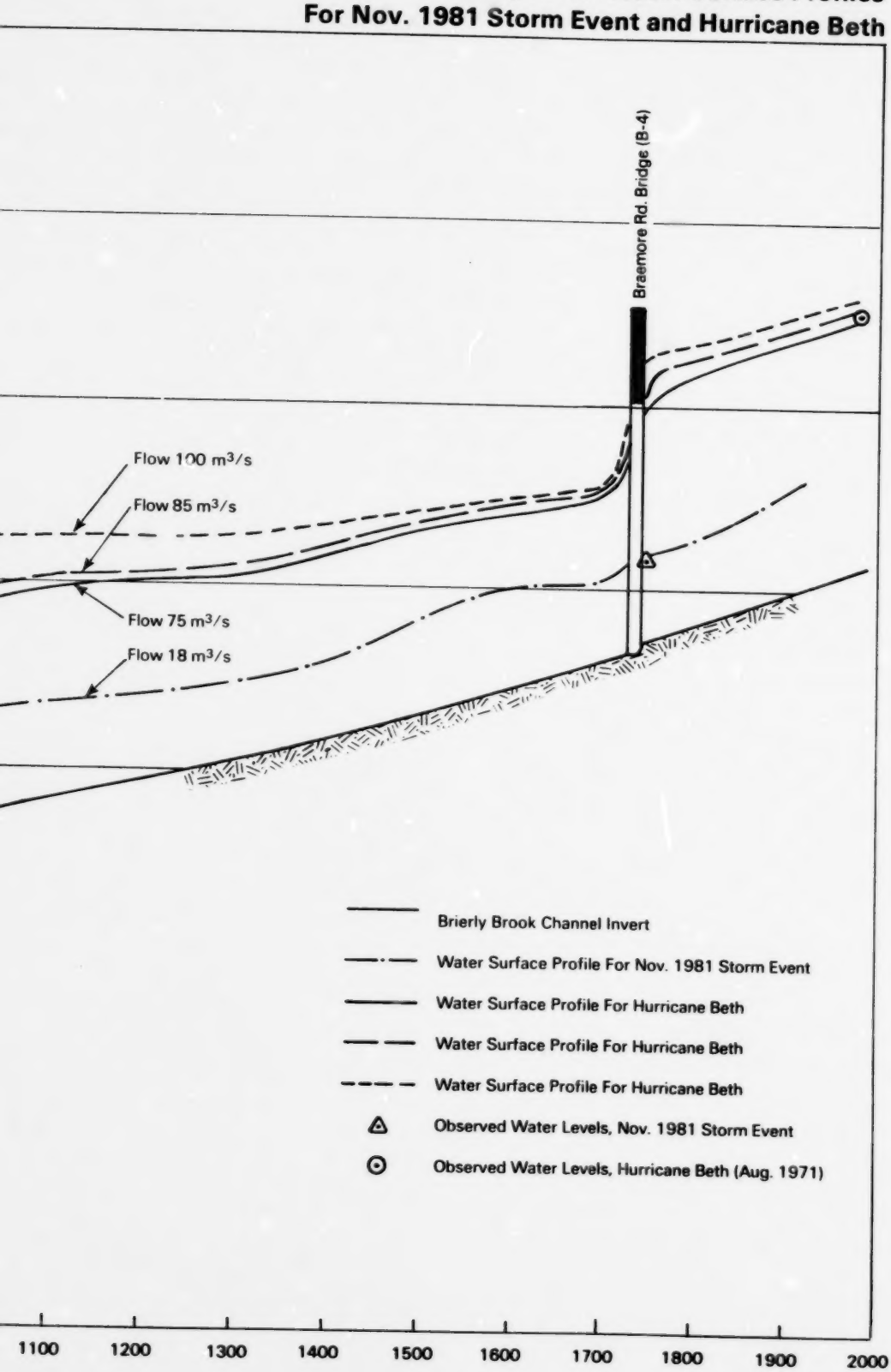
Figure 7–2

Brierly Brook Water Surface Profiles For Nov. 1981 Storm Event and Hurricane Beth



f Brierly Brook

Figure 7-3

Rights River Water Surface Profiles
For Nov. 1981 Storm Event and Hurricane Beth

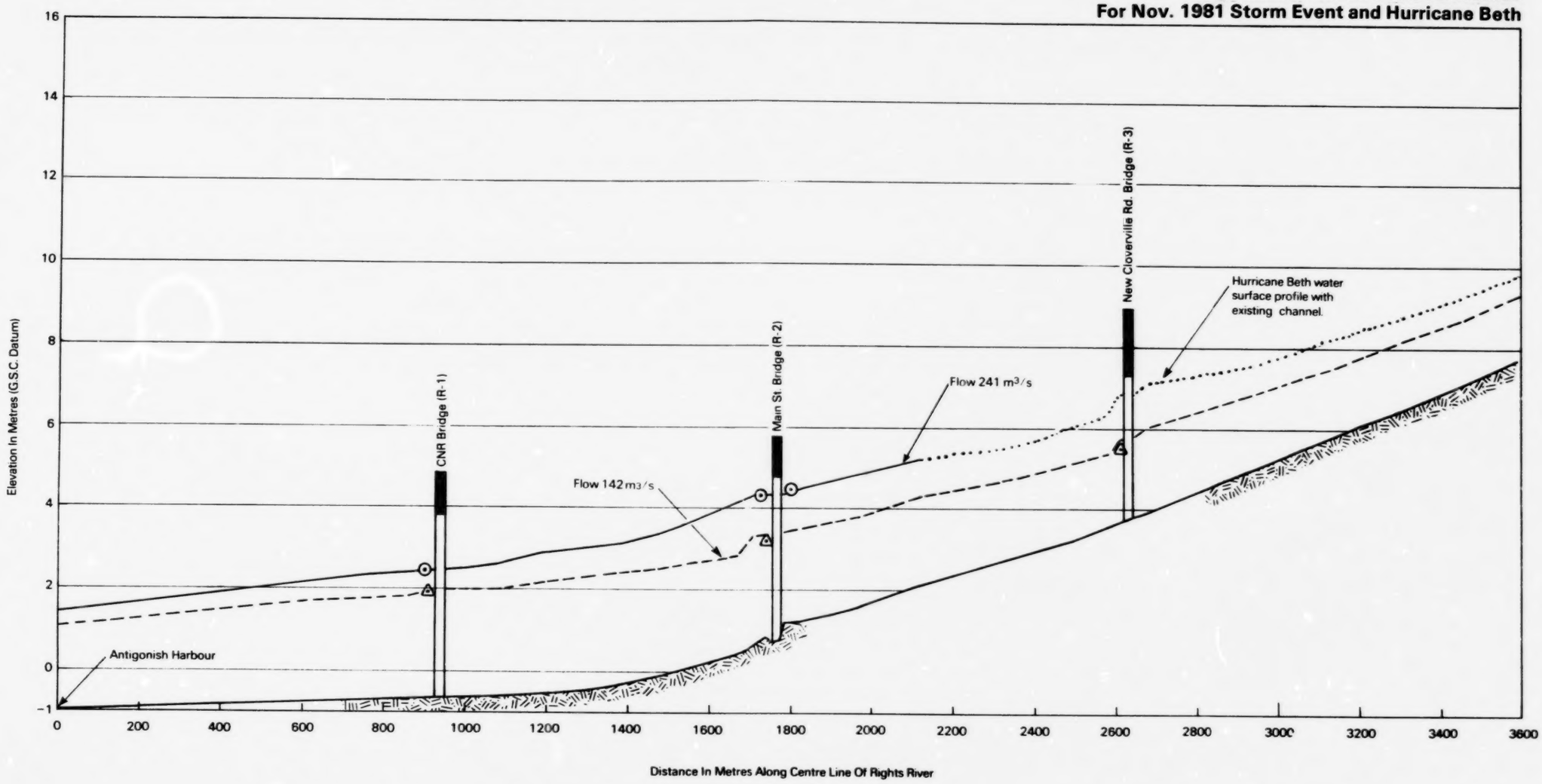


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Figure 7-4

West River Water Surface Profiles
For Nov. 1981 Storm Event and Hurricane Beth

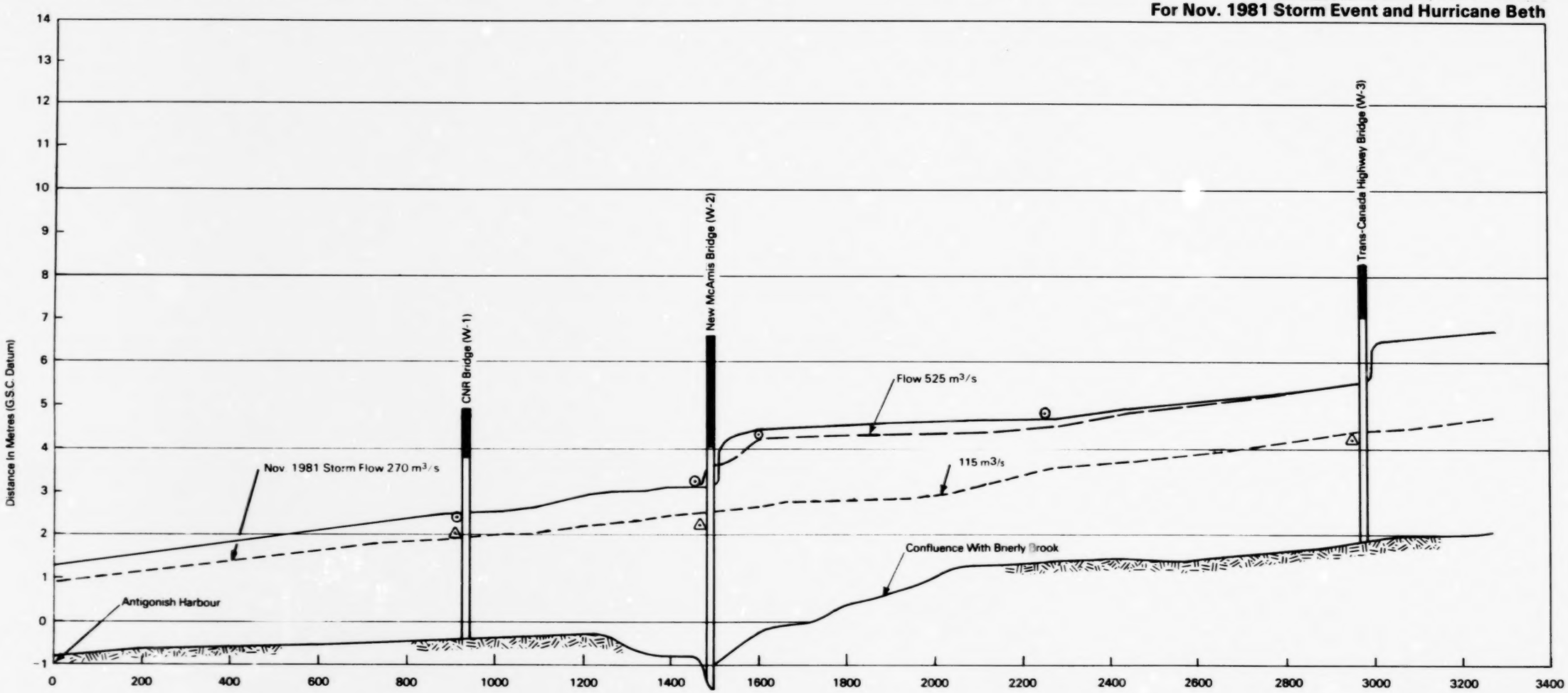

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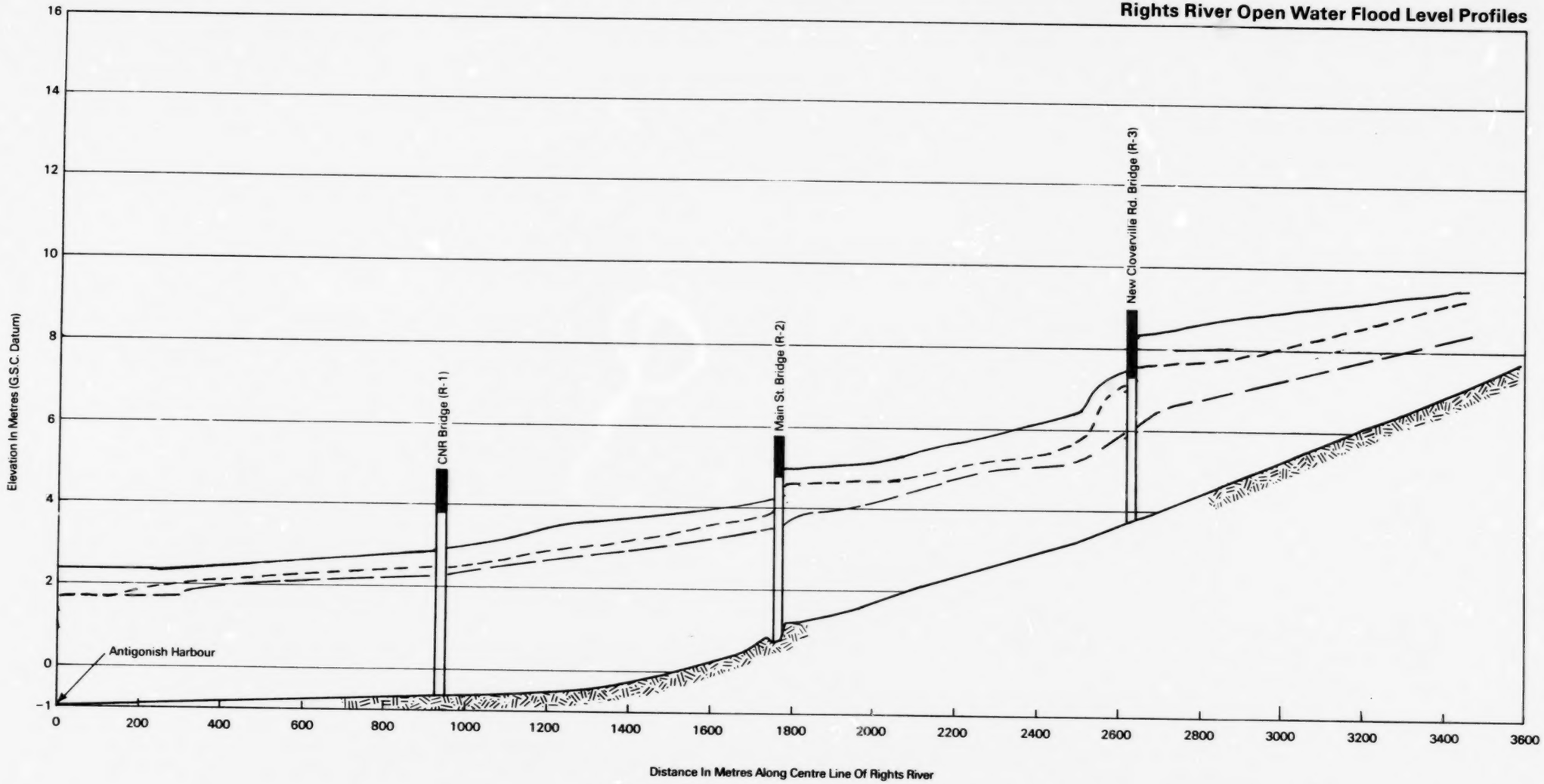
Figure 7-5

Rights River Open Water Flood Level Profiles



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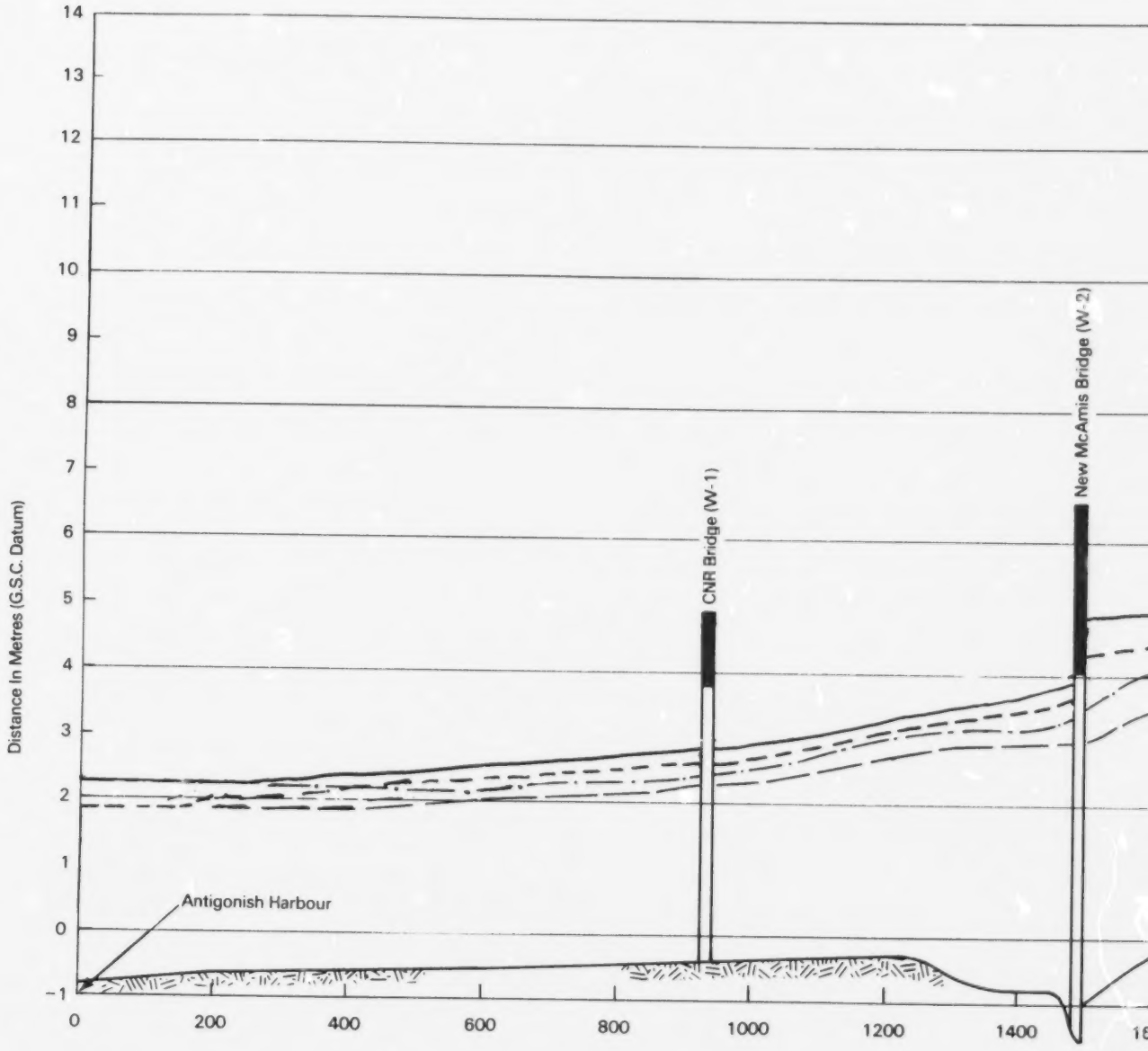


Figure 7-6

West River Open Water Flood Level Profiles

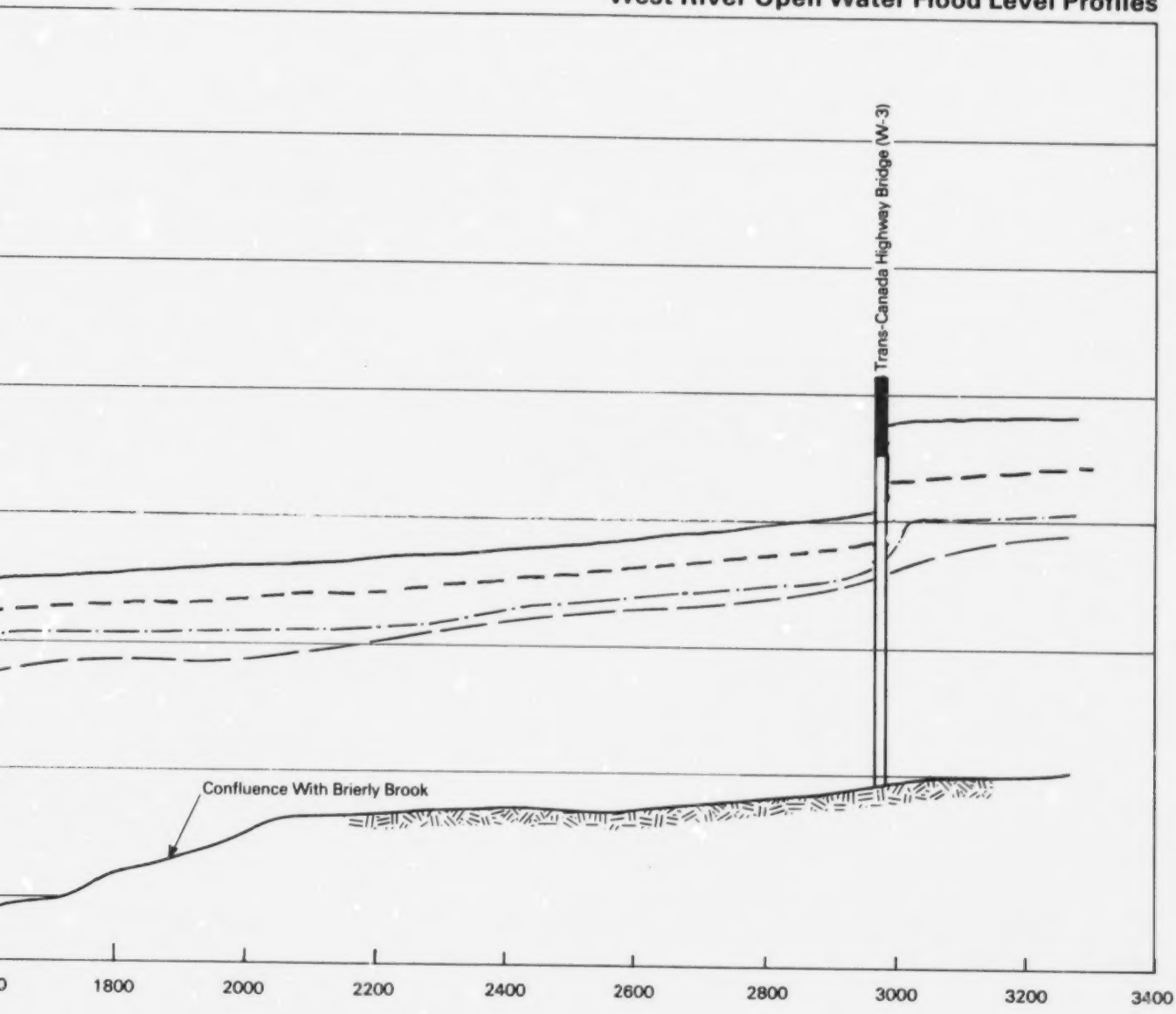
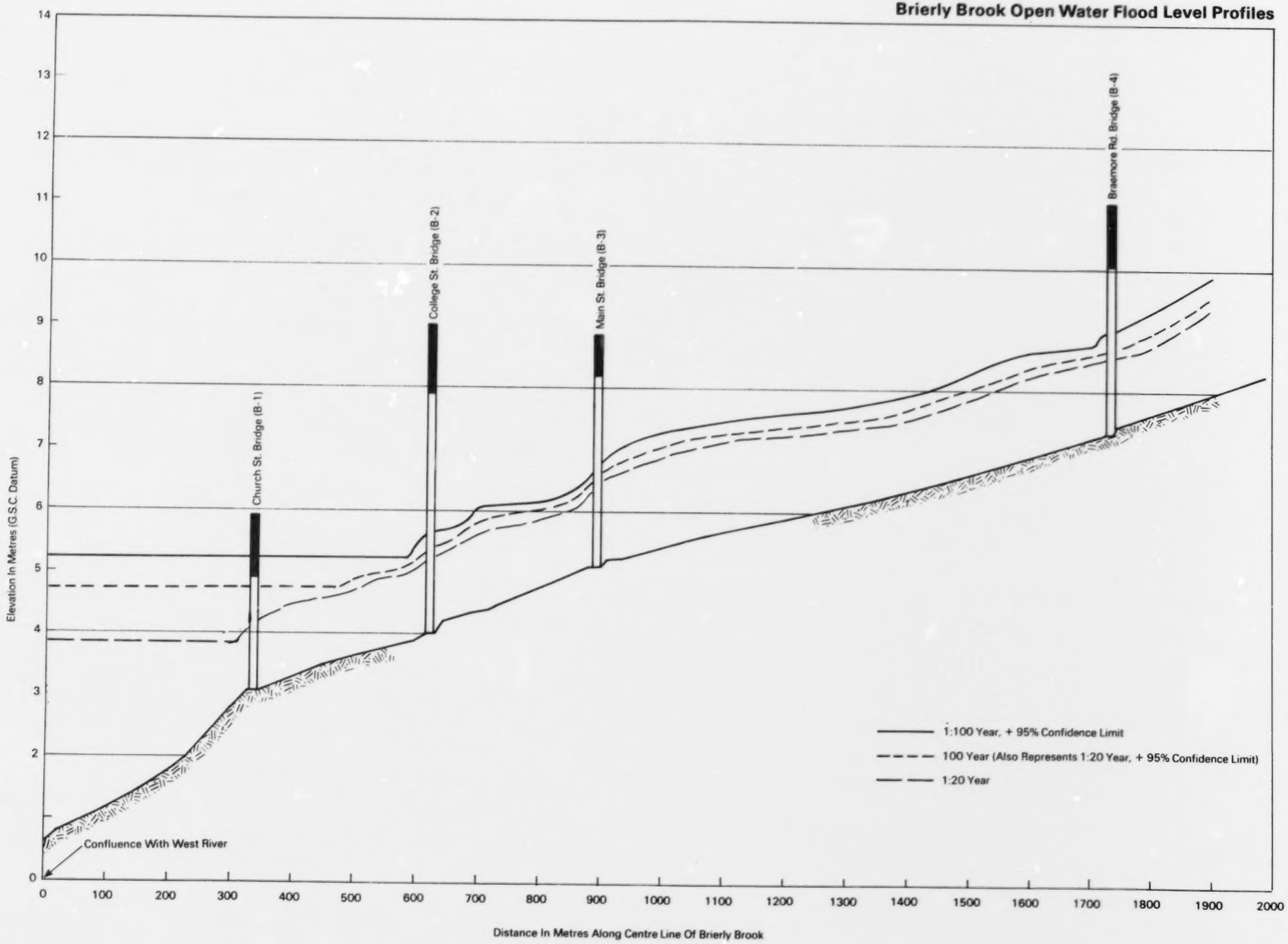


Figure 7-7

Brierly Brook Open Water Flood Level Profiles


Elevation In Metres (G.S.C. Datum)
Church St. Bridge (B-1)
College St. Bridge (B-2)
Main St. Bridge (B-3)
Braemore Rd. Bridge (B-4)
Confluence With West River
1:100 Year, + 95% Confidence Limit
100 Year (Also Represents 1:20 Year, + 95% Confidence Limit)
1:20 Year
Distance In Metres Along Centre Line Of Brierly Brook

CHAPTER 8 - REMEDIAL MEASURES

8.1 Ice Conditions

A major factor causing ice problems in Antigonish is that the downstream reaches of the West River and the Rights River near the harbour remain frozen much longer than upstream reaches and the tributaries, such as Brierly Brook. This hinders clearing of ice from the upstream reaches and consequently creates an upstream ice jam threat which may be present in Antigonish for many years to come.

Although it is currently impractical to clear ice from these lower reaches of the river, these reaches do have one redeeming feature. They are relatively open and undeveloped, and have served through time as a good location for storing ice and conveying flood flows which have spilled over the banks from ice jams in the intervale lands. In most years, ice is carried through the upper reaches to the interval without development of serious upstream ice jams. In other years, however, meteorological factors combine to maintain a strong ice sheet for some distance upstream from the harbour mouth, and this forms a barrier to the passage of ice and discharge into the interval. It appears desirable, for reducing flood damage, to initiate some actions to safely clear ice from the upper reaches without causing jams in the lower reaches. This might be effected by ice retention measures. It may be useful to employ land use regulations (zoning) to prohibit certain developments in flood-prone areas. There may be works such as channel modifications or relief channels that would alleviate jams and flood damages. Assessing long term ice control options through systematic study and observations may be useful.

Brierly Brook

Although ice jams at the Church Street Bridge appear to be composed of large pieces of the ice sheet which forms between Church Street and College Street, the ice cover below the bridge and on the West River may help to initiate jams at Church Street and has certainly retarded the flow of ice through the bridge.

Remedial measures which may be considered to reduce ice problems begin in the reach below Church Street, and include:

1) widening and lowering the south bank near the rapids at the end of Court Street.

2) similar work to the north bank about 100 m (320 ft.) above the West River.

The object of this work would be to provide several locations for ice and water to spill easily into the flood plain rather than having it contained completely in the channel and causing a back up to Church Street.

The potential for jamming of large ice pieces at the bridge may still exist even if the lower channel is sufficiently clear to carry ice from above Church Street. This problem may be tackled as it occurs (or before if a break up forecast is given) by:

3) breaking the ice sheet from Church Street to Main Street prior to an increase in stream flow.

4) positioning a backhoe or ball-and-crane at the bridge to break large pieces of ice enabling it to flow through the bridge during break up.

These latter options are contingent upon rapid response to potential ice jam problems - which may occur at night or more quickly than expected. Hence, further protection can be provided by:

5) adding several culverts across Church Street north of the bridge to bypass flood waters to the lower channel.

6) reconstructing the Church Street Bridge to provide a larger unobstructed opening.

It would be appropriate to initiate the above mentioned activities 1, 2, 3, and 4 before completing an assessment of activities 5 and 6. It would also be most appropriate to initiate an ice observation program. Information on break up timing and processes coming from this program would be useful in determining the potential for detaining ice within the channel above Main Street Bridge, and the design and location of detention works.

Rights River

Formation of ice jams on the Rights River is influenced by river ice conditions below the Main Street Bridge. Damaging floods occur when this ice remains consolidated up to the area of Main Street. Less damaging floods occur when the ice has broken up below Main Street. In the former case, there is no harmless outlet for ice and flood flows and they carry over Main Street at Columbus Field. In the latter case,

overflow onto marsh lands behind St. Andrews Street business is relatively harmless.

Remedial actions which may be considered include:

1) breaking/weakening the ice sheet from about 150 m upstream of Main Street Bridge to about 300 m below the bridge following forecasts of high flows for the area and/or forecasts of precipitation and mild temperatures (snowmelt).

2) positioning a work crew at the bridge to clear any subsequent ice obstruction that might occur at the bridge.

Flood damage reduction options which may also be considered for this area include:

3) flood proofing of several structures along Elm Street.

4) flood proofing Main Street at Elm Street with an objective of keeping Main Street open to traffic if ice jam reduction measures are unsuccessful.

This work would possibly involve: partial regrading of the intersection and an adjacent parking lot; provision of culverts beneath Main Street; preparation of a broad, shallow relief channel to and from this intersection.

The Rights River at the Cloverville Road Bridge does not appear to be a site where ice jams will occur frequently. The jam of March 1982 may have been initiated at a small set of rapids about 50 m (165 ft.) below this bridge or on ice remaining on the bed at this spot following breakup in February 1982. It would be appropriate to:

5) examine this area periodically during the winter and ensure that ice accumulations do not remain in this area.

6) position a crane and wrecking ball at this location during breakup to ensure unobstructed ice movement through this area.

Ice observations in 1982 indicated that a portion of the ice contributing to jamming at Cloverville Road and Main Street had come from above the confluence of the South Rights River, and that minor ice jams had occurred on both branches above the town. This suggests that there may be natural ice detention areas in these reaches and that development of their detention capability could be beneficial. Ice conditions and the channel in this area have not been studied in any detail, however, and a program of ice observations would be appropriate before considering additional action on this remedial measure.

West River

Since the McAmis Bridge was replaced, this location is not considered a likely site for ice jamming. Although some ice jamming may occur in the reach downstream of St. Andrews Street due to harbour ice, this is likely to be relatively harmless as the ice would likely spill into the interval lands. Consequently, remedial measure to prevent flooding from ice jams do not appear warranted from available information.

8.2 Open Water Conditions

The results of the hydraulic analysis carried out for open water condition form the basis for the delineation of flood prone areas within the Town of Antigonish. Flooding along Brierly Brook due to rainfall and rainfall-and-snowmelt events has diminished since the Brierly Brook dam was built. Although the new Rights River channel and the New McAmis Bridge across the West River have reduced the extent of flooding in the immediate areas, flooding can still occur within the Town from these two rivers.

The following structural and non-structural remedial measures might be considered to alleviate flood damages from the West and Rights Rivers:

Structural Measures

- Investigate the benefits of building the flood retardation dams originally proposed by the Department of Regional and Economic Expansion (Ref. 3) and shown in Figure 2-2, to alleviate flooding in Antigonish. These structures could also be used for ice detention.

- Localized berming or flood proofing of the flood prone structures located upstream of Main Street and Cloverville Road due to flooding from the Rights River; localized berming or flood proofing of the flood prone structures located downstream of Church Street due to flooding from the West River.

Non-Structural Measures

- Acquisition of flood prone property.
- Enforcement of floodplain regulation.

appendix a

PLANS AND ELEVATIONS
OF BRIDGE STRUCTURES

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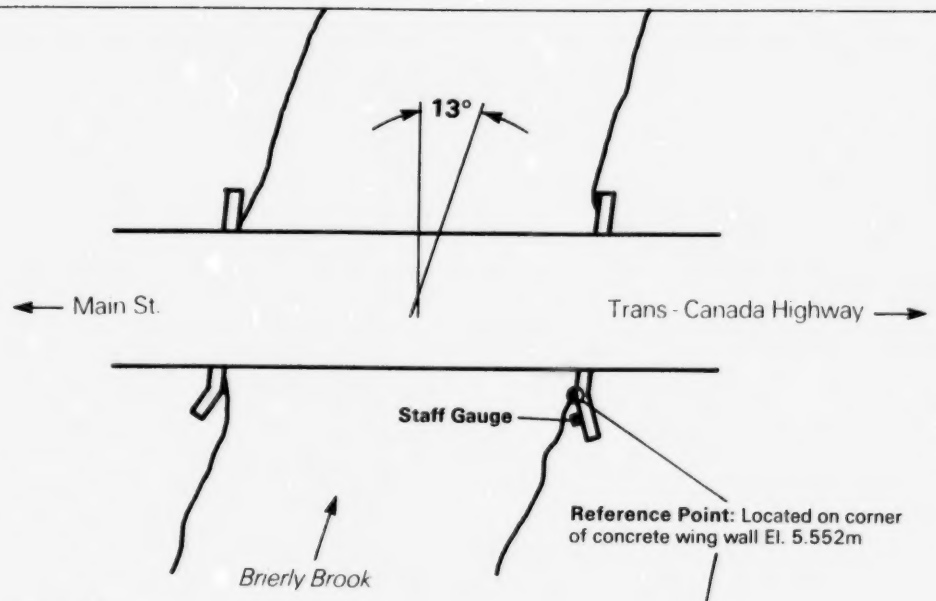
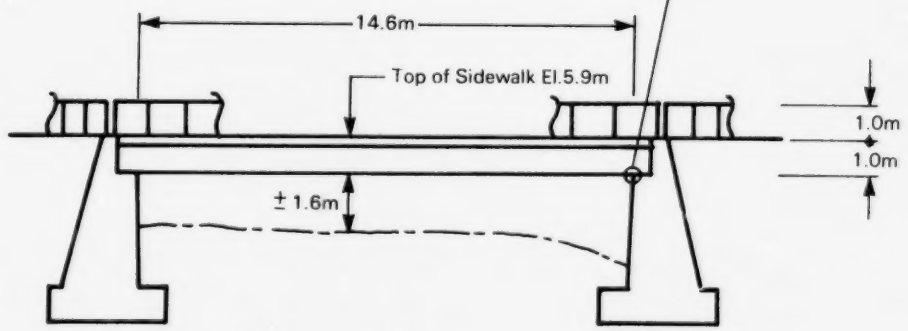


Plan (not to scale)



Elevation (scale 1:200)

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Figure A-1
Church Street Bridge Across Brierly Brook (Bridge B-1)

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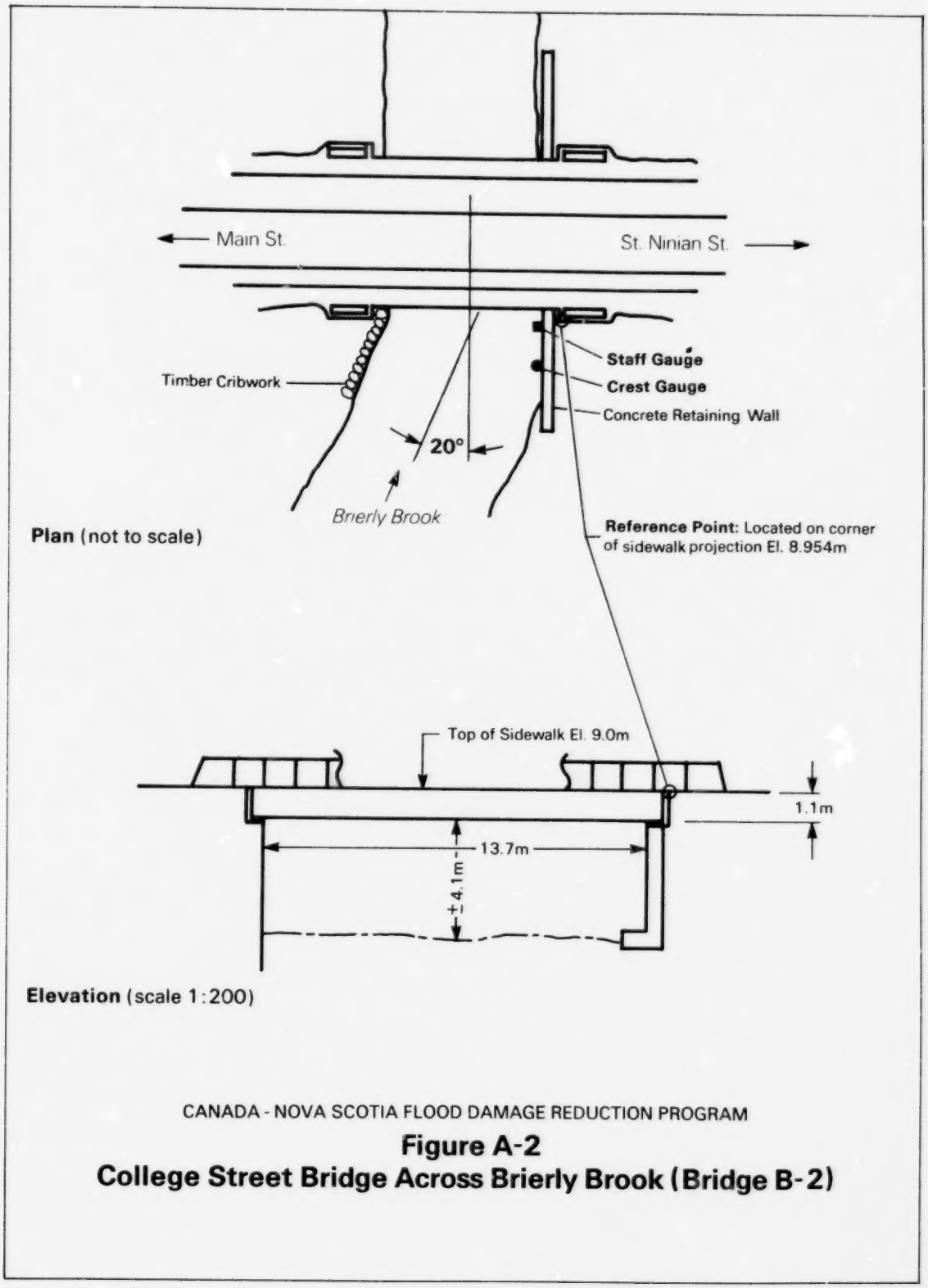

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Figure A-2
College Street Bridge Across Brierly Brook (Bridge B-2)

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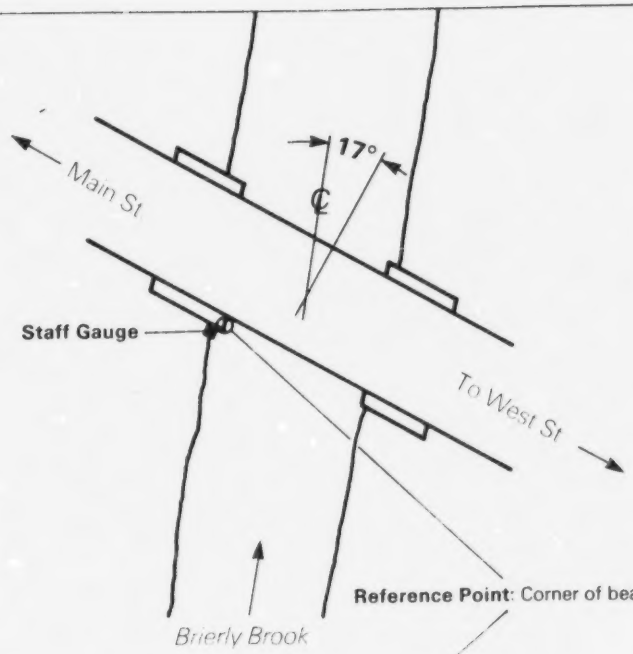
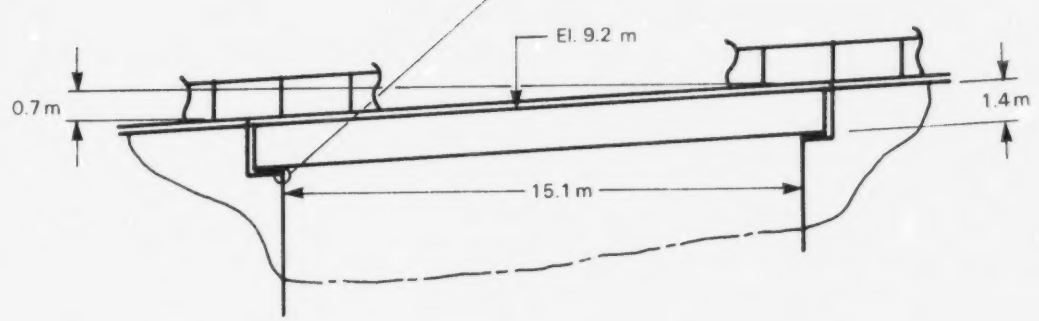


Plan (not to scale)



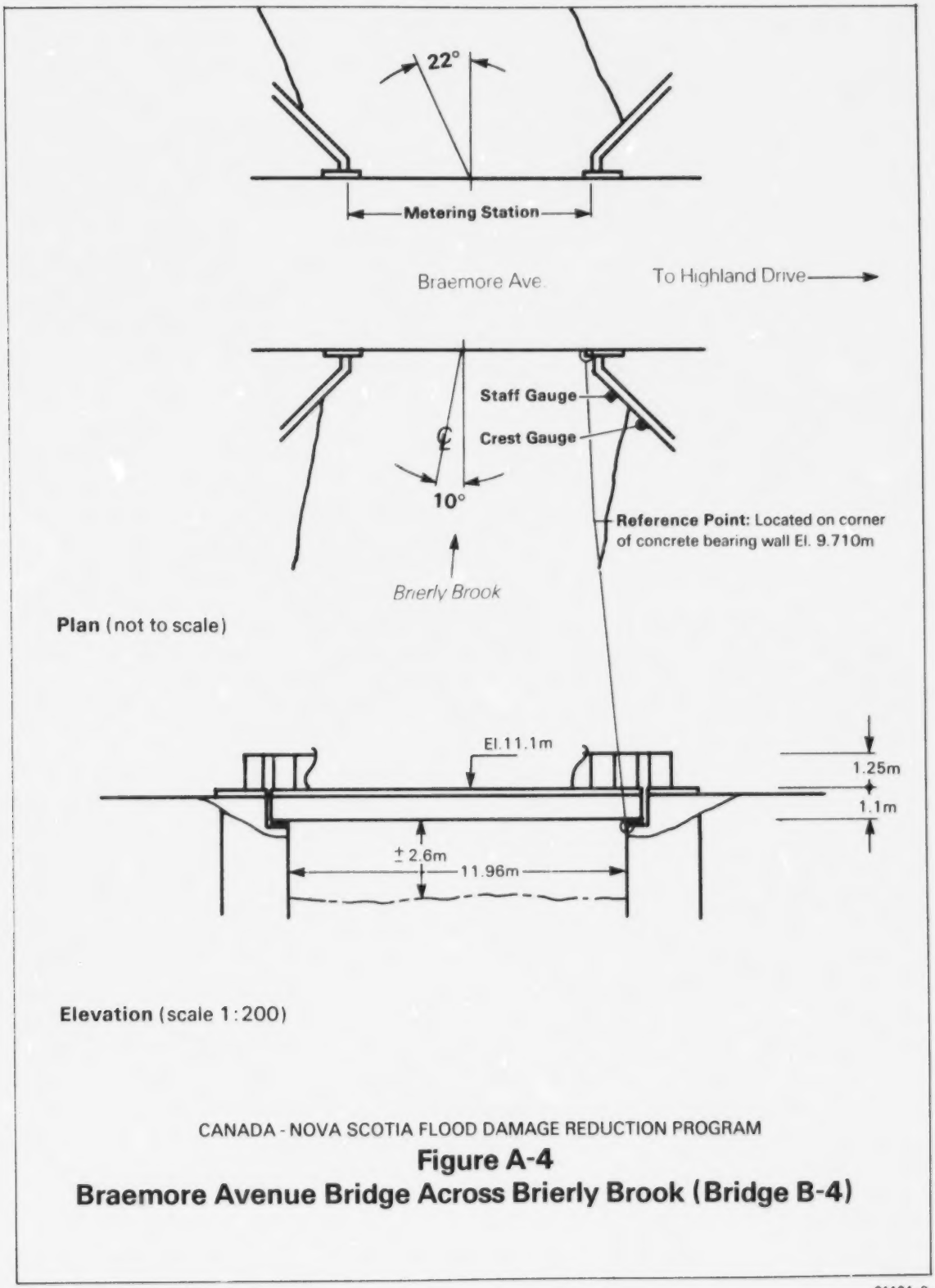
Elevation (scale 1:200)

CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-3

Main Street Bridge Across Brierly Brook (Bridge B-3)

01194-0

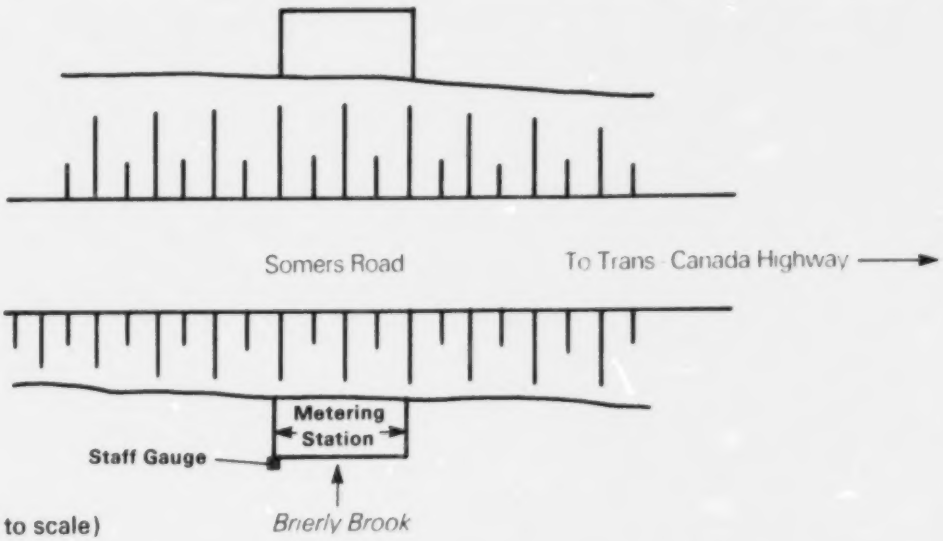


CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

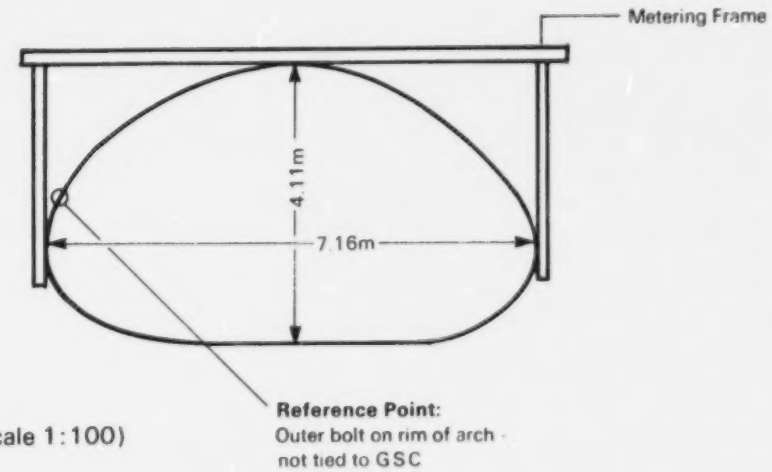
Figure A-4

Braemore Avenue Bridge Across Brierly Brook (Bridge B-4)

01194-0



Plan (not to scale)



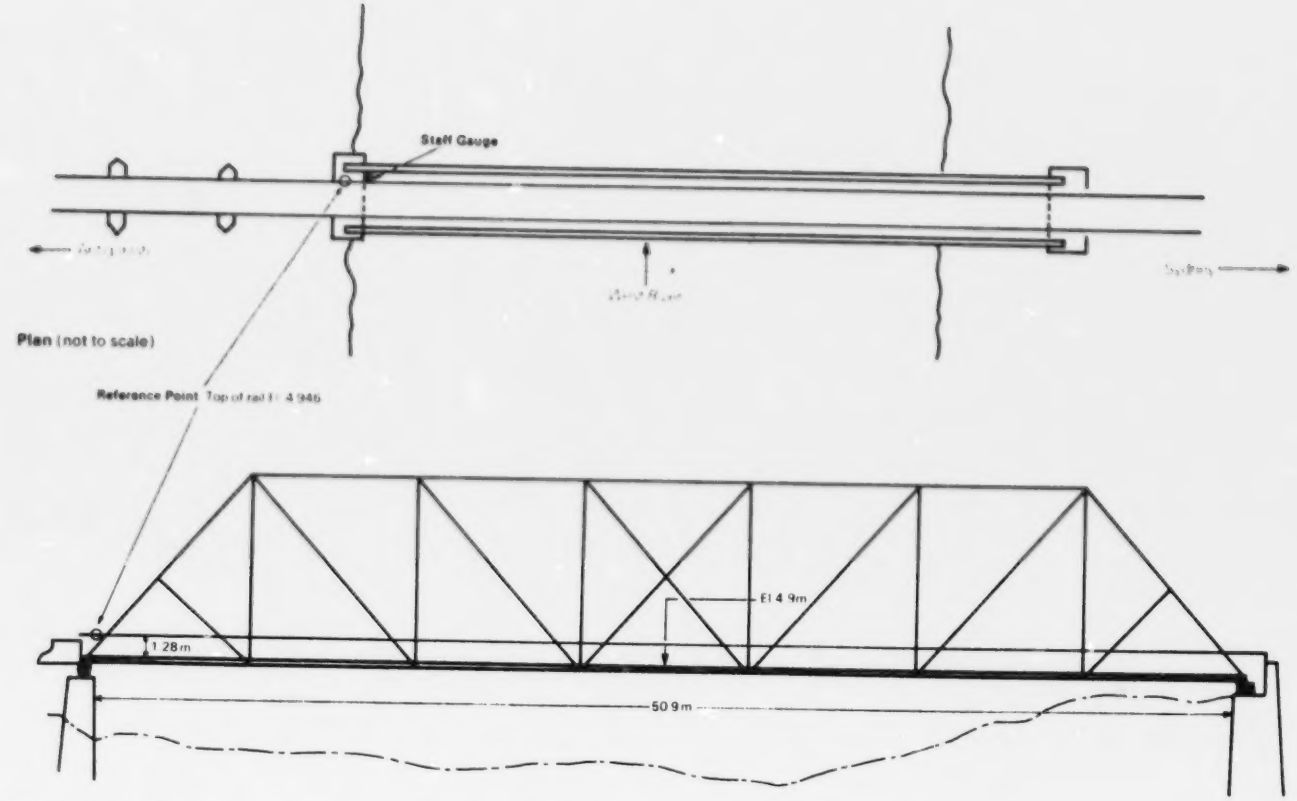
Elevation (scale 1:100)

CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-5

Somers Road Bridge Across Brierly Brook (Bridge B-6)

01194-0

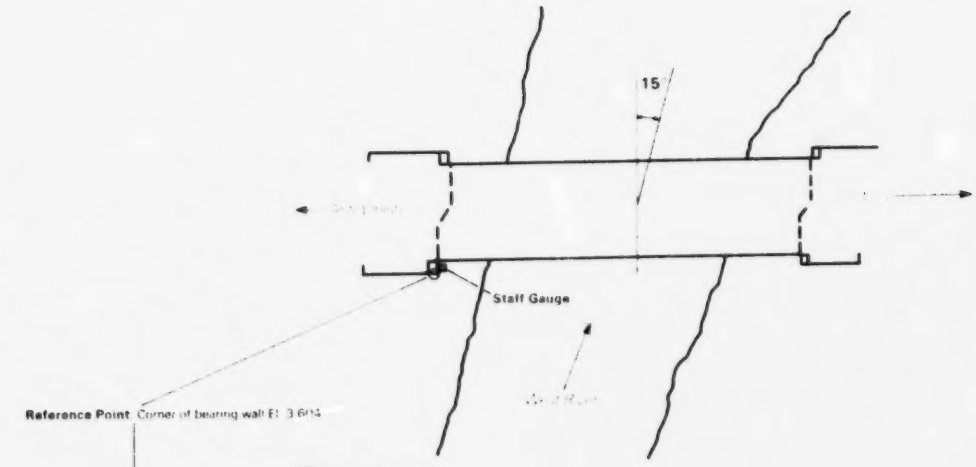


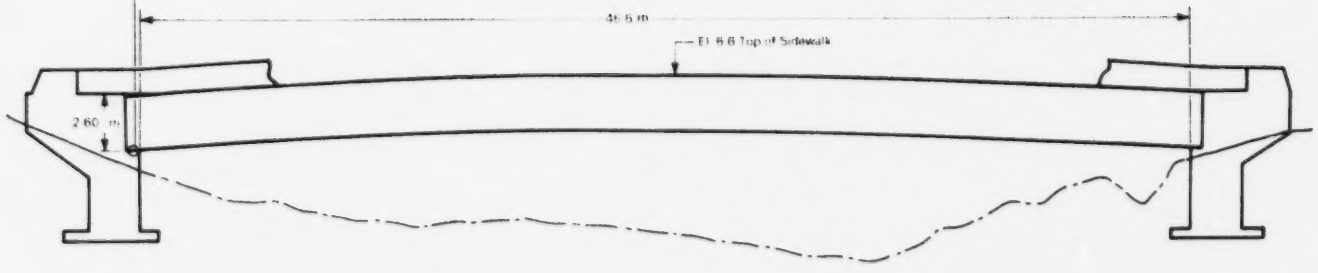
CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-6

Canadian National Railway Bridge Across The West River (Bridge W-1)

J1194.0



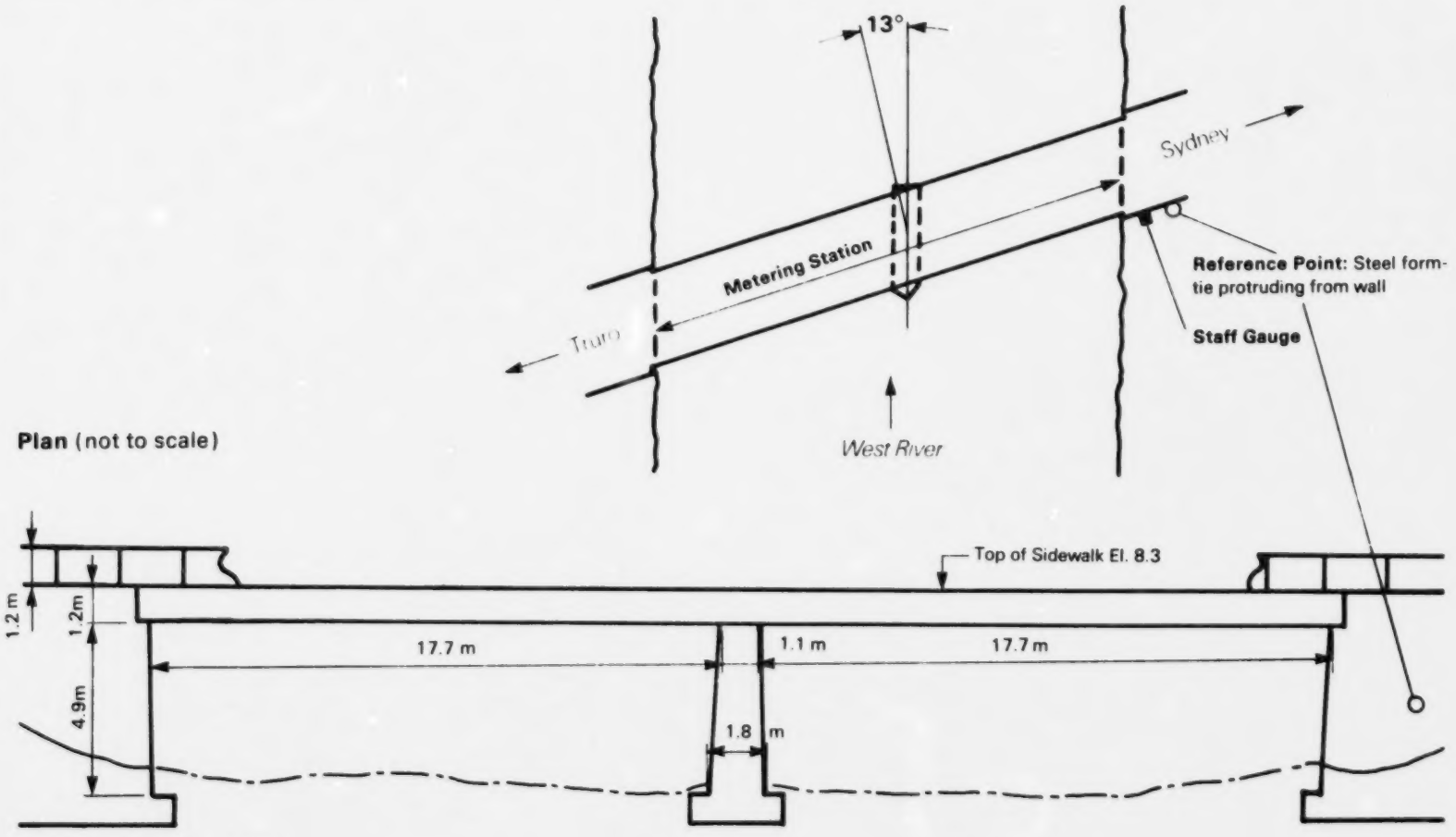


Elevation (scale 1 200)

CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-7

McAmis Bridge Across The West River (Bridge W-2)

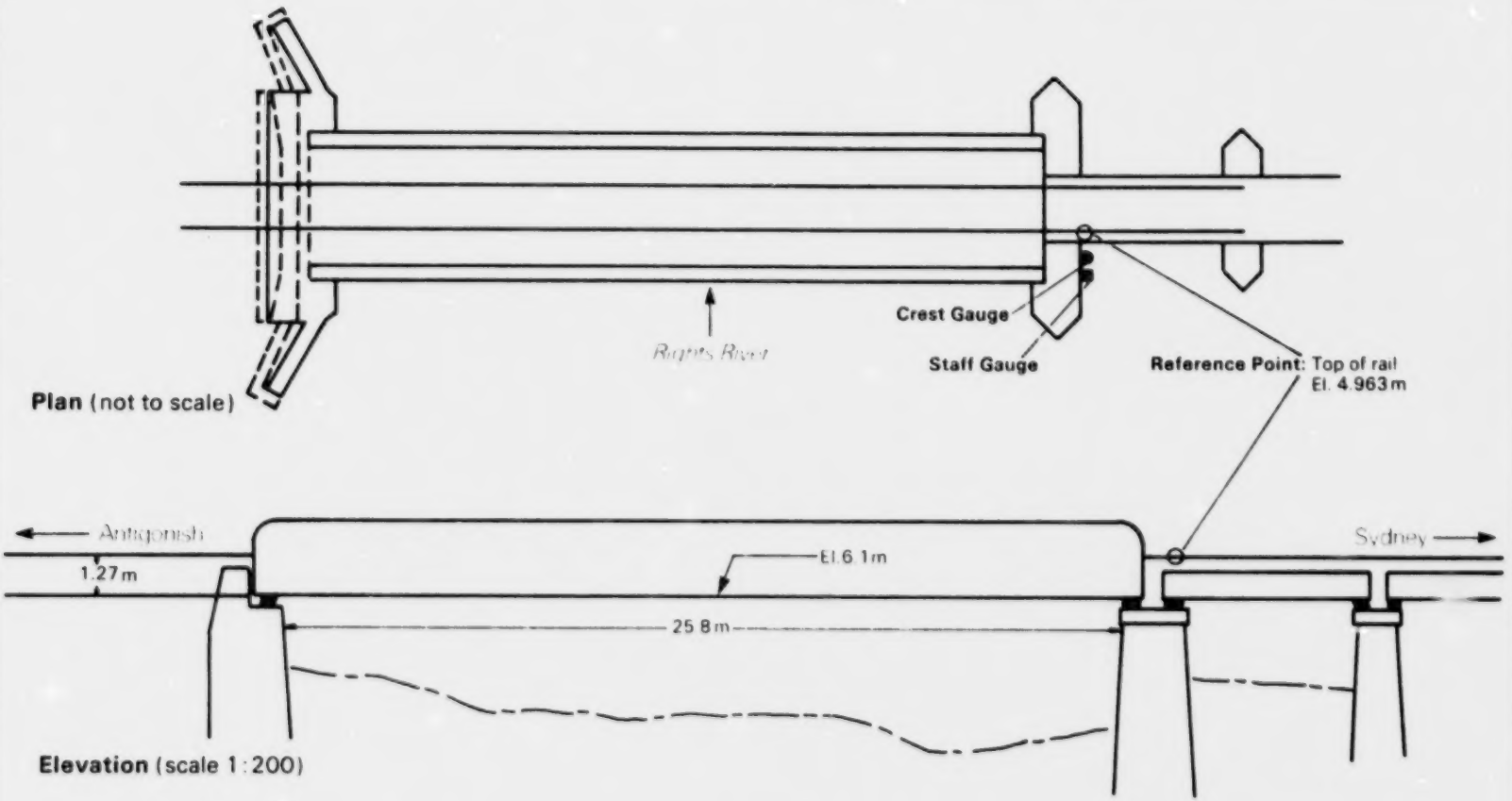


CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-8

Trans - Canada Highway Bridge Across the West River (Bridge W–3)

01194-0

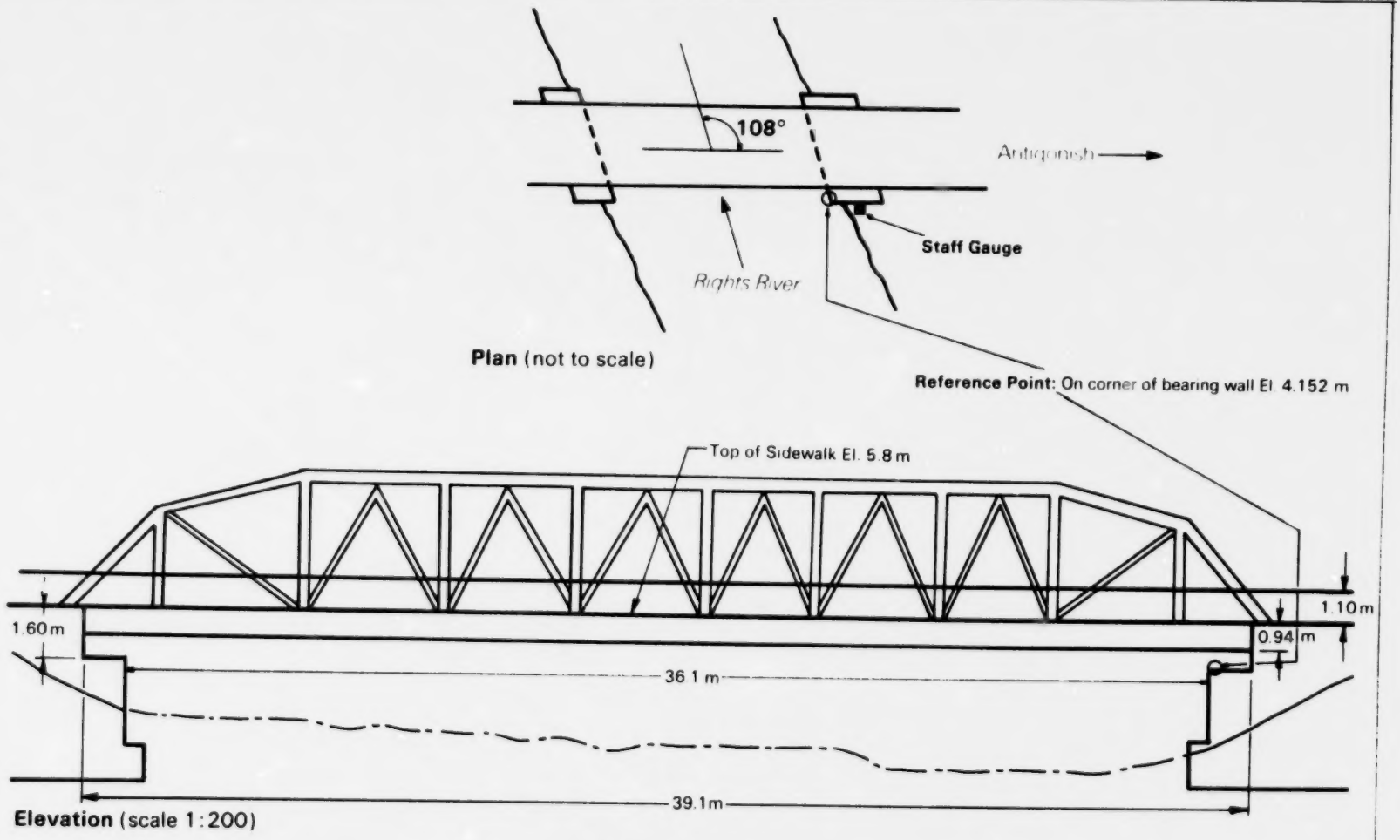


CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-9

Canadian National Railway Bridge Across The Rights River (Bridge R-1)

01194 0

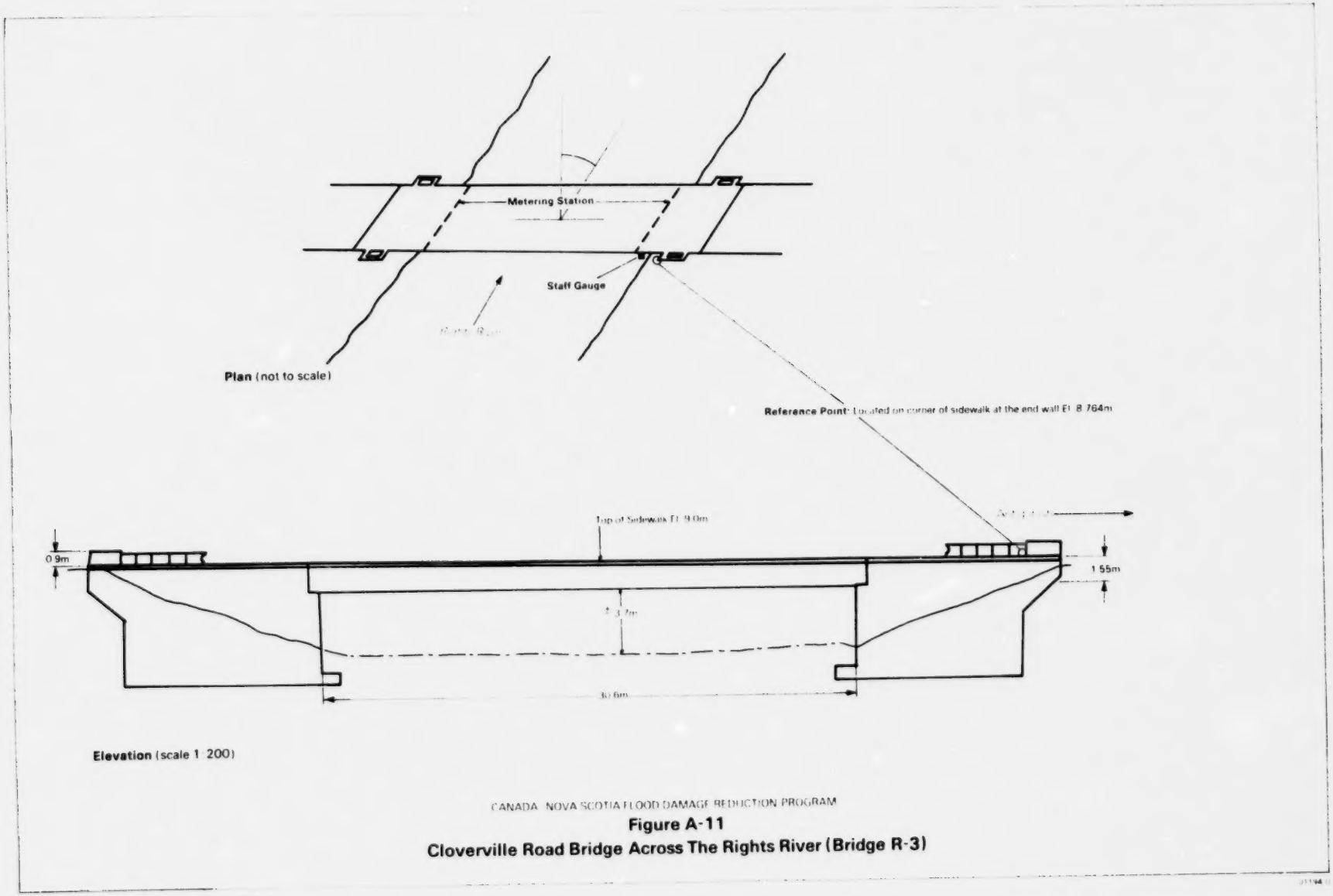


CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-10

Main Street Bridge Across The Rights River (Bridge R-2)

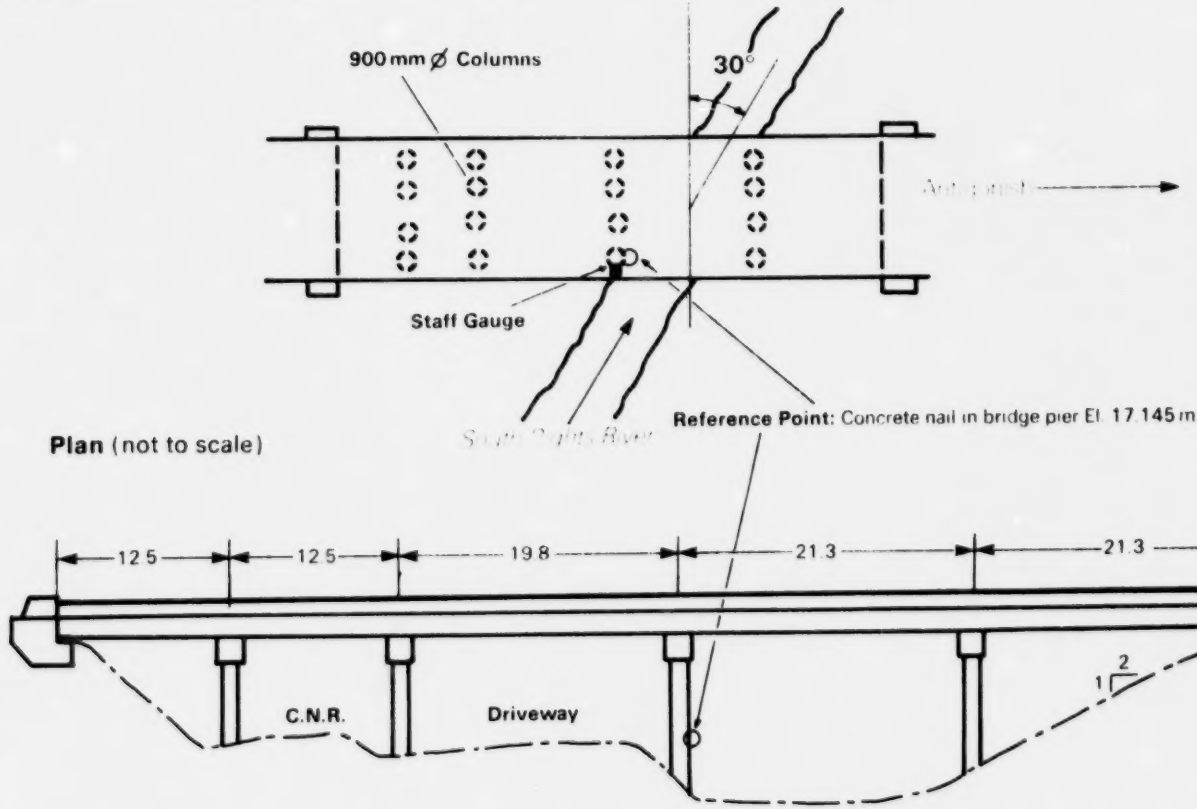
01194-0



CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-11

Cloverville Road Bridge Across The Rights River (Bridge R-3)



CANADA - NOVA SCOTIA FLOOD DAMAGE REDUCTION PROGRAM

Figure A-12
Route 245 Bridge Across The Rights River (Bridge R-4)

01194 0

appendix b

TERMS OF REFERENCE
FOR THE
HYDROTECHNICAL STUDY
OF THE
ANTIGONISH AREA FLOOD PLAIN

Canada - Nova Scotia
Technical Committee
on Flood Risk Mapping

May 1980

Plan Objectives
(as contained in the Terms of Reference)

Section 3

STUDY REQUIREMENTS

The basic purpose of this study is to provide reliable estimates of the 1:20 year and 1:100 year open water flood profiles for Rights River downstream of its confluence with the South Rights River, West River downstream of Highway 104 and Brierly Brook downstream of the dam.

The study to be carried out by the Consultant will make maximum utilization of related studies carried out by various consultants and government agencies, and of the guidelines established for the program. Maximum utilization should be made of existing data, described, in part, in Appendix B.

The study consists of a thorough review of existing information, the selection of an appropriate mathematical model(s), a detailed evaluation of existing data, the identification of data voids, the collection and compilation of new data necessary for the study, the analysis/interpretation of the data and the derivation of the 1:20 and 1:100 year flood profiles. More specifically, the consultant shall:

1) Carry out a thorough review of existing information in order to obtain an understanding of the flooding problem and to make maximum use of existing data.

A summary of existing data is described , in part, in Appendix B.

2) Evaluate the significance of various factors affecting flooding in the Antigonish area.

These factors include:

Plan Objectives
(as contained in the Terms of Reference)

(a) Tides: tides may or may not have a significant effect on flooding in the Antigonish area. Nevertheless, it is thought that it would be convenient to begin modelling the floodplain from that point when the tidal regime is not materially affected by freshwater flow. This would eliminate the need to establish a stage-discharge relation at the downstream end of the model. Accordingly, the tidal regime (including astronomical and meteorlogical factors) in Antigonish Harbour will have to be assessed.
(b) Ice: identify ice jam locations and the significance of ice jams on flood levels.
(c) Physiography and Cultural Influences: the flood risk, and flood reduction effect of the dam on Brierly Brook must be considered. Additional factors for consideration include, but are not limited to, infilling of land along the West River, structures across the rivers, and straightening of Rights River in the vicinity of College Street.
(d) Freshwater Flows: the Regional Flood Frequency Analysis provides estimates of peak flows associated with frequencies of 1:20 and 1:100 years for the following locations: 1) at the dam Brierly Brook, 2) mouth of Brierly Brook at West River, 3) mouth of Rights River, 4) West River, upstream of Brierly Brook, and 5) West River, downstream of Brierly Brook.

Because of the dam on Brierly Brook the natural flow estimates given in the Regional Flood Frequency

Plan Objectives
(as contained in the Terms of Reference)

Analysis are not expected to be useful for determining flood water levels, below the dam. It is expected, therefore, that the study consultant will use a hydrologic routing model to improve the accuracy of flow estimates for the 1:20 and 1:100 year floods. This will require flow measurements to calibrate the model, and to validate the calibration.

(3) Recognizing the significance of the various factors, the limitations in the data base, and other constraints, design a strategy to produce 1:20 and 1:100 year recurrence interval flood profiles.

(4) Select an appropriate mathematical hydraulic model(s) capable of simulating the hydraulic behaviour of the river system under study.

The following general guidelines should be considered:

(a) The model(s) must take into consideration the level of accuracy discussed in the "Hydrologic and Hydraulic Procedures for Flood Plain Delineation".[7]

(b) All major derivations of model parameters should be thoroughly expalined.

(c) The model should be adaptable to simulating the effects of ice jams.

(d) Consideration should be given to selecting a model that can be used later for the evaluation of possible structural charges including channelization, flood control dams, dykes, instream structures such as bridges/culverts, and flood

Plan Objectives
(as contained in the Terms of Reference)

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(4) Select an appropriate mathematical hydraulic model(s) capable of simulating the hydraulic behaviour of the river system under study.

The following general guidelines should be considered:

(a) The model(s) must take into consideration the level of accuracy discussed in the "Hydrologic and Hydraulic Procedures for Flood Plain Delineation".[7]

(b) All major derivations of model parameters should be thoroughly expalined.

(c) The model should be adaptable to simulating the effects of ice jams.

(d) Consideration should be given to selecting a model that can be used later for the evaluation of possible structural changes including channelization, flood control dams, dykes, instream structures such as bridges/culverts, and flood

plain modifications such as, improved drainage. The model should also be capable of evaluating the impact on water levels resulting from additional fill in the flood plain. The evaluation of such future changes is not a part of this contract.
(5) Design, coordinate and manage a field program for the purposes of calibrating and verifying the mathematical model(s) selected, taking into full consideration the availability and quality of existing data.

Liaison should be maintained with the Water Survey of Canada during field investigations to ensure that (a) the hydrometric station on the Rights River is operational during the course of the survey and (b) that the hydrometric data are interpreted as quickly as possible. Water Survey of Canada could be consulted on the collection of hydrometric data through the Flood Risk Mapping Technical Committee. Stream flows and resulting water surface elevations must be determined throughout the study area during high runoff conditions. Ground surveys will be required to determine the nature and extent of the features which affect the exchange of water between the river and the flood plain.

The consultant shall also consider the Land Registration and Information Service horizontal control data and Geodetic Survey of Canada vertical control data.

Plan Objectives
(as contained in the Terms of Reference)

All channel cross-sections for the study should extend to the limits of the flood plain to be mapped. A contract has been awarded to Atlantic Air Survey Limited to produce 1:2000 scale topographic maps with 1.0 meter contour intervals for the Antigonish area flood plain. The Consultant should seriously consider the possibility of deriving cross-sections from the aerial photography when the maps are being compiled. In the event this approach is used, some field surveys will still be required in the river channel, and to check the cross-sections.

(6) Based on a review of all pertinent data, undertake office studies as are necessary to fill data voids.

(7) The selected model(s) should be calibrated and verified, using split sample techniques. Documentation on recent floods should be used to the extent possible.

(8) Produce the 1:20 and 1:100 year recurrence interval open water flood profile for the study reach.

(9) Superimpose ice jam events (as indicated by historical events) on profiles calculated in (8).

(10) Carry out a sensitivity analyses of the flood profiles with a view toward identifying overall error.

Plan Objectives
(as contained in the Terms of Reference)

Factors to be considered include:
(a) Errors in the hydrologic input 1:20 and 1:100 year flood hydrographs).
(b) Errors in model parameters such as Manning's roughness coefficient, expansion and contraction loss coefficients and channel geometry.
(c) Errors due to any assumptions made.
(d) Errors due to tidal conditions.
(e) Sensitivity to the effect of initial storage levels in any off-channel storages.

(11) Examine the frequency of occurrence of flows resulting from Hurricane Beth which occurred in August, 1971.

(12) Place the 1:20 and 1:100 year recurrence interval flood lines on large scale maps provided by the Technical Committee.

(13) Suggest, but do not study, possible remedial measures to alleviate the flood damage problem.

(14) Provide monthly progress reports and discuss the various aspects of the investigation with the Technical Committee, as required or as requested by the Program Manager.

(15) Provide six copies of the draft report.

(16) Provide 50 copies of the final report.

appendix c

TYPICAL CROSS-SECTIONS
FOR THE WEST AND RIGHTS RIVERS
AND BRIERLY BROOK

NOTE: All cross-sections plotted looking downstream from left to right bank

RIGHTS AND WEST RIVER HEC-2 MODEL
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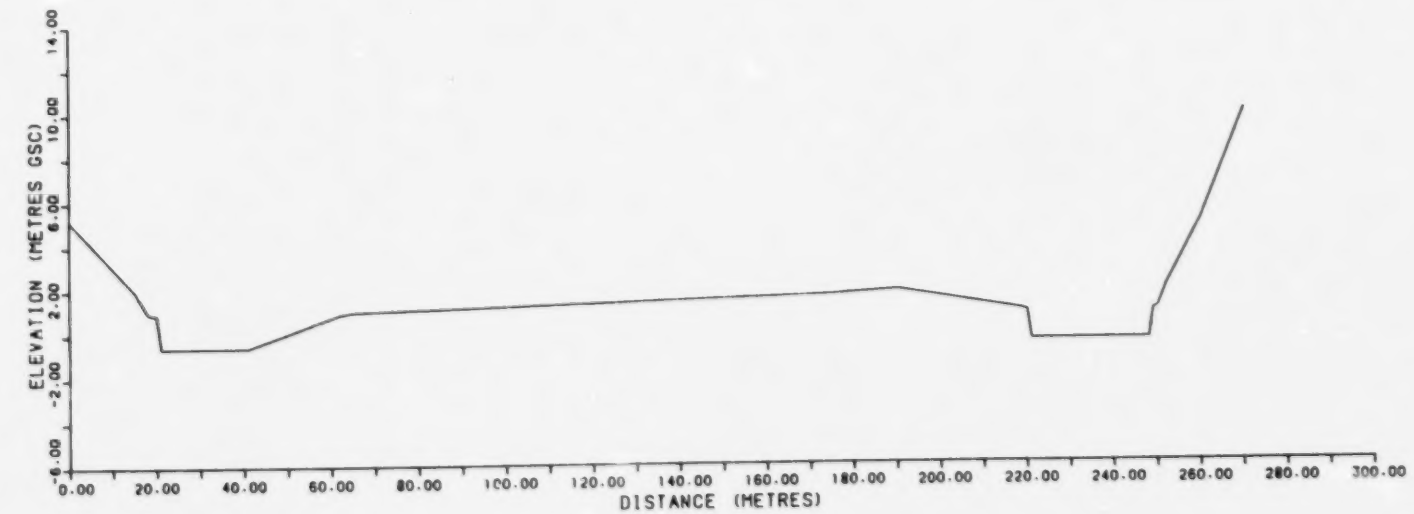
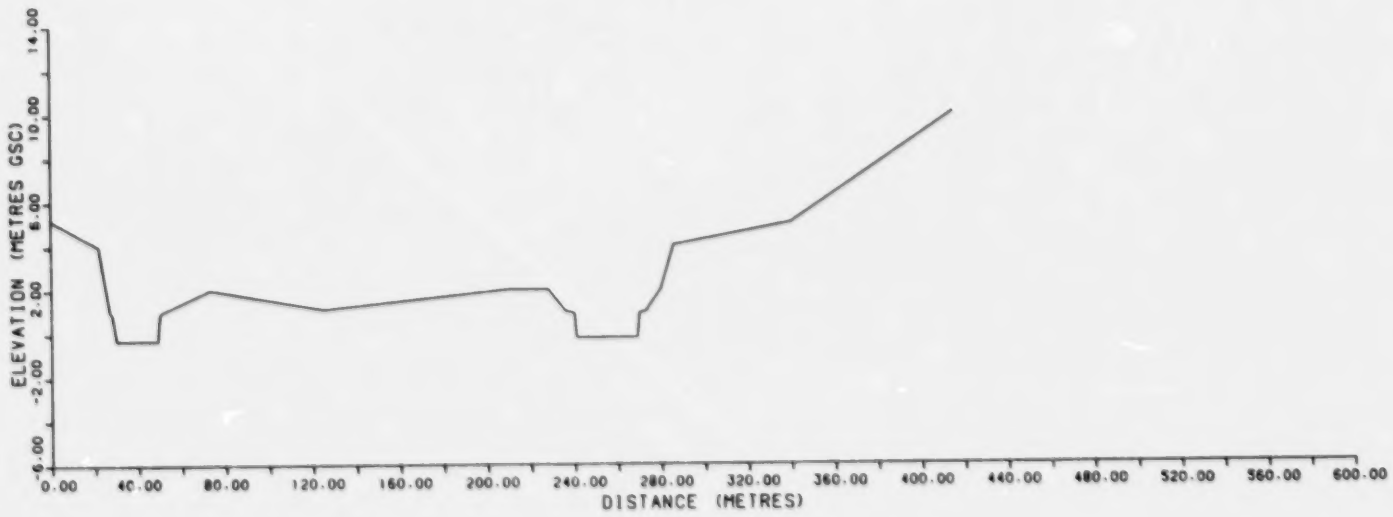


RIGHTS AND WEST RIVER HEC-2 MODEL
CROSS SECTION NUMBER 1388



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RIGHTS RIVER HEC-2 MODEL

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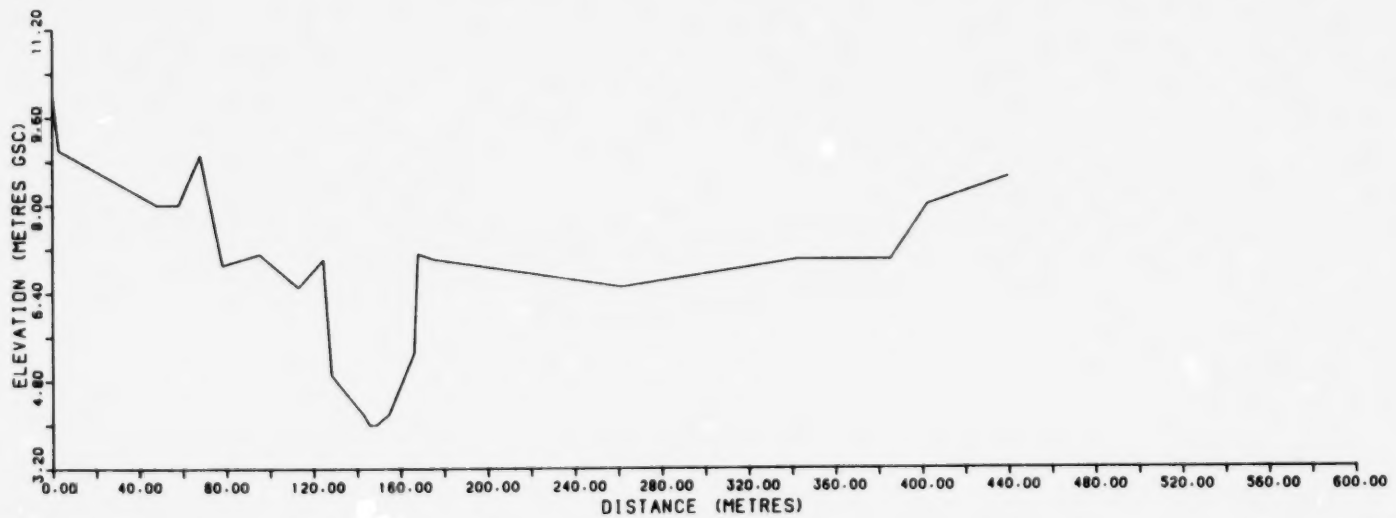

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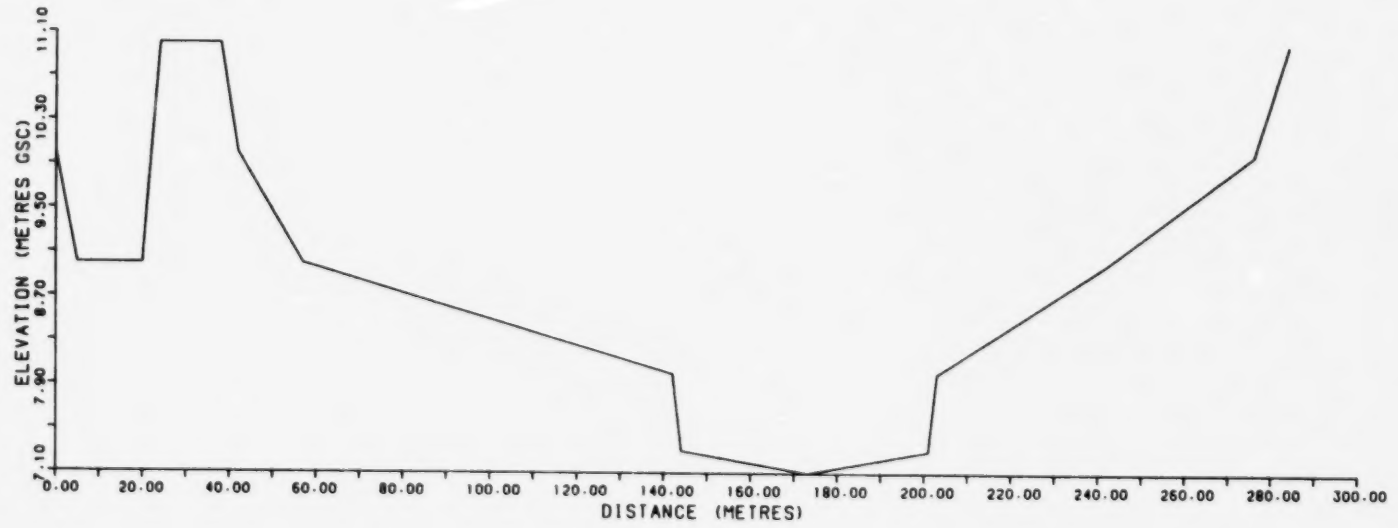

RIGHTS RIVER HEC-2 MODEL

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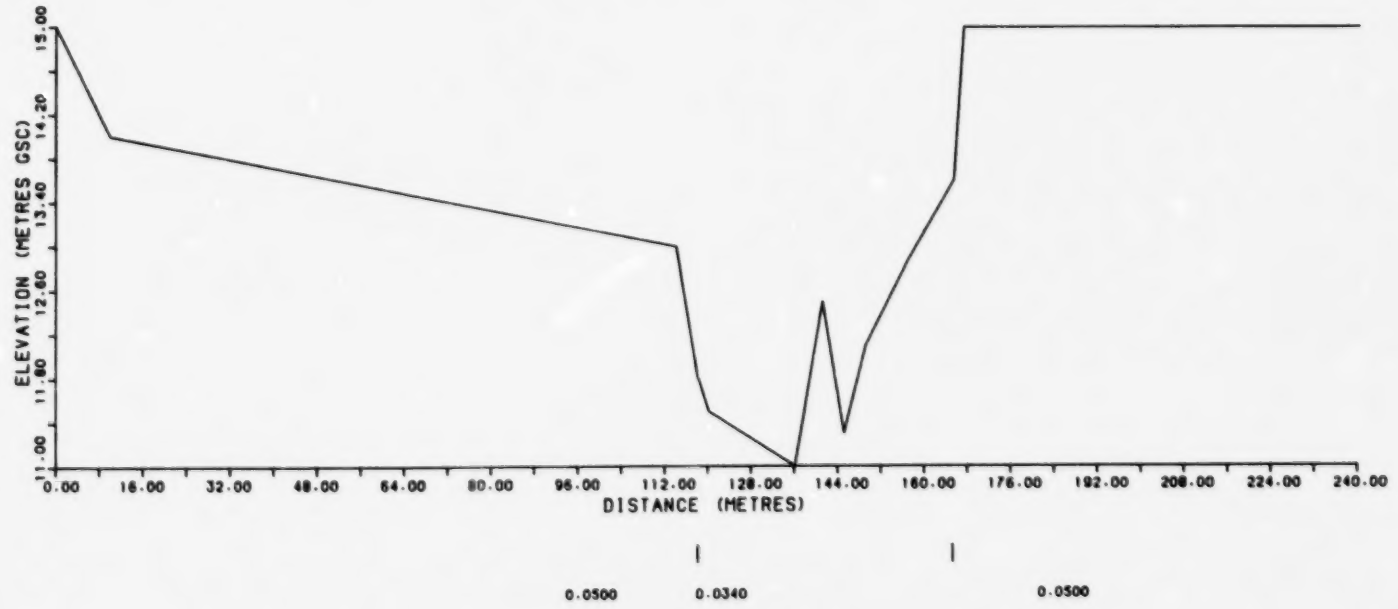

WEST RIVER HEC-2 MODEL

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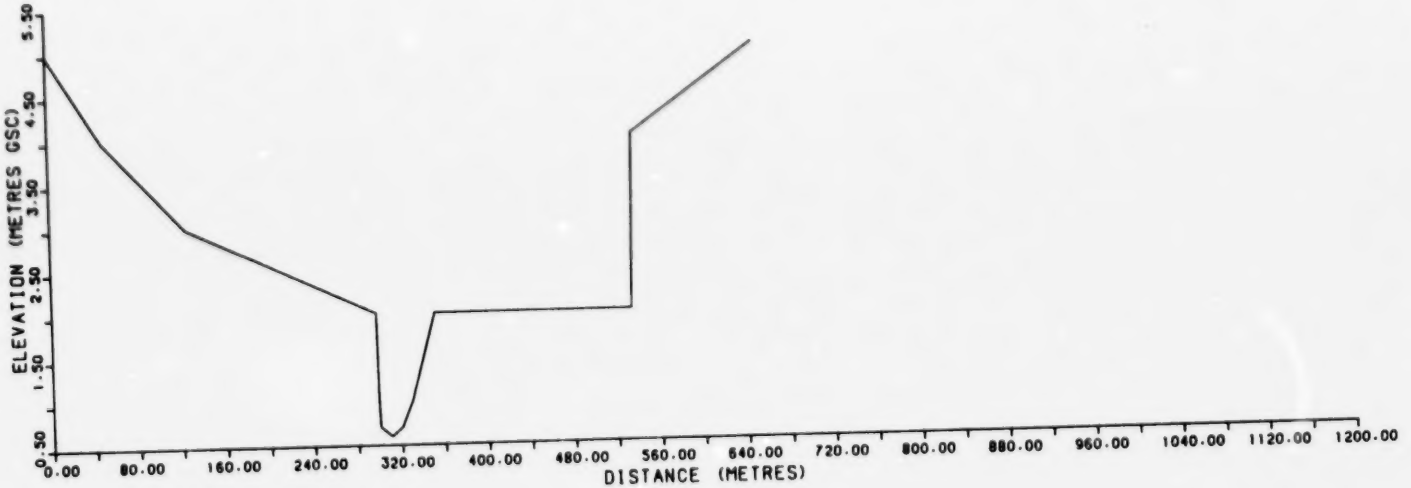

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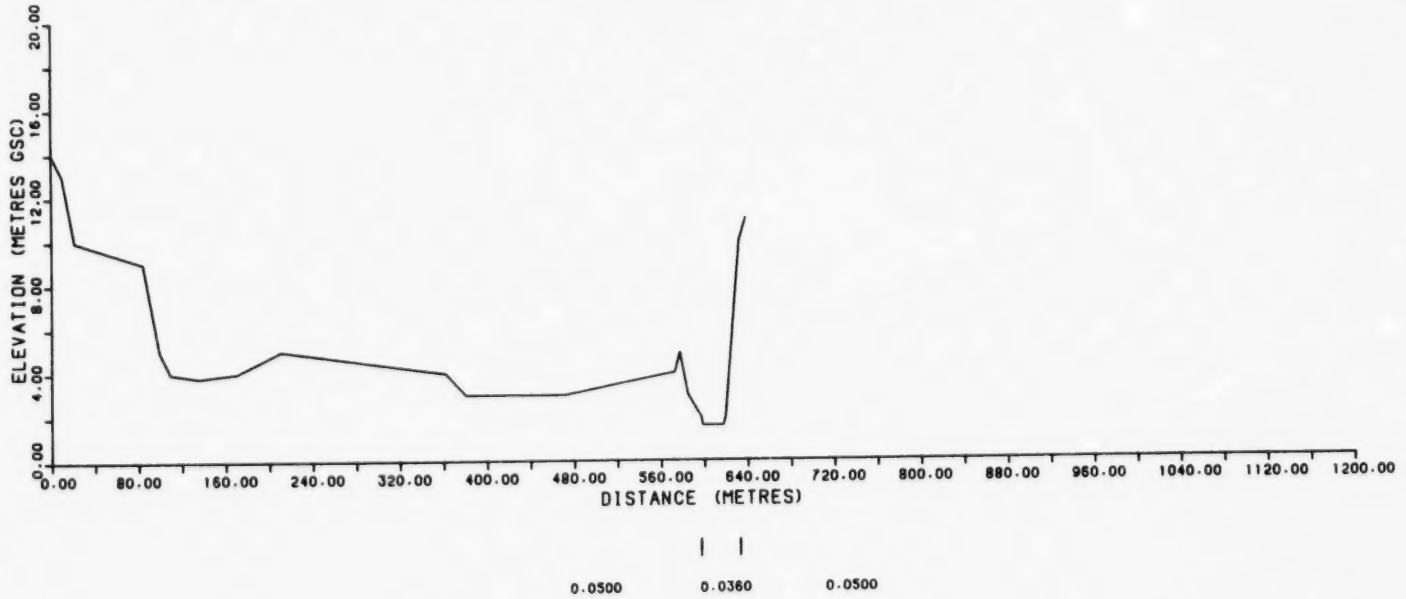

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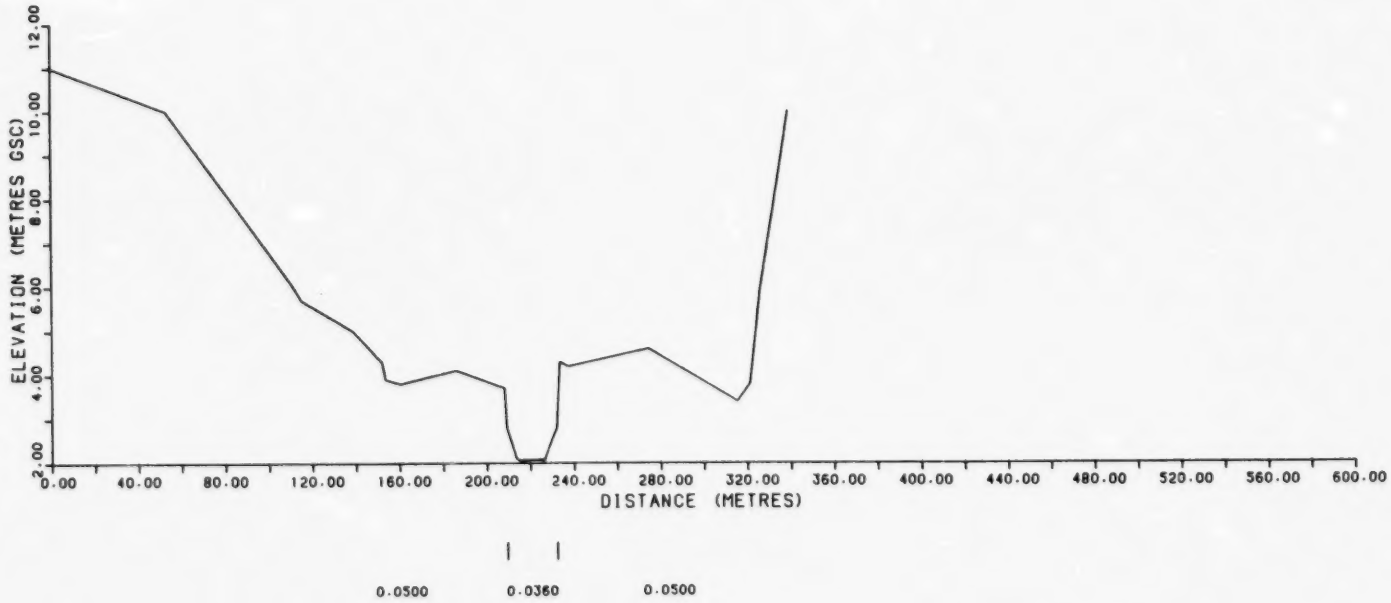

BRIERLY BROOK HEC-2 MODEL

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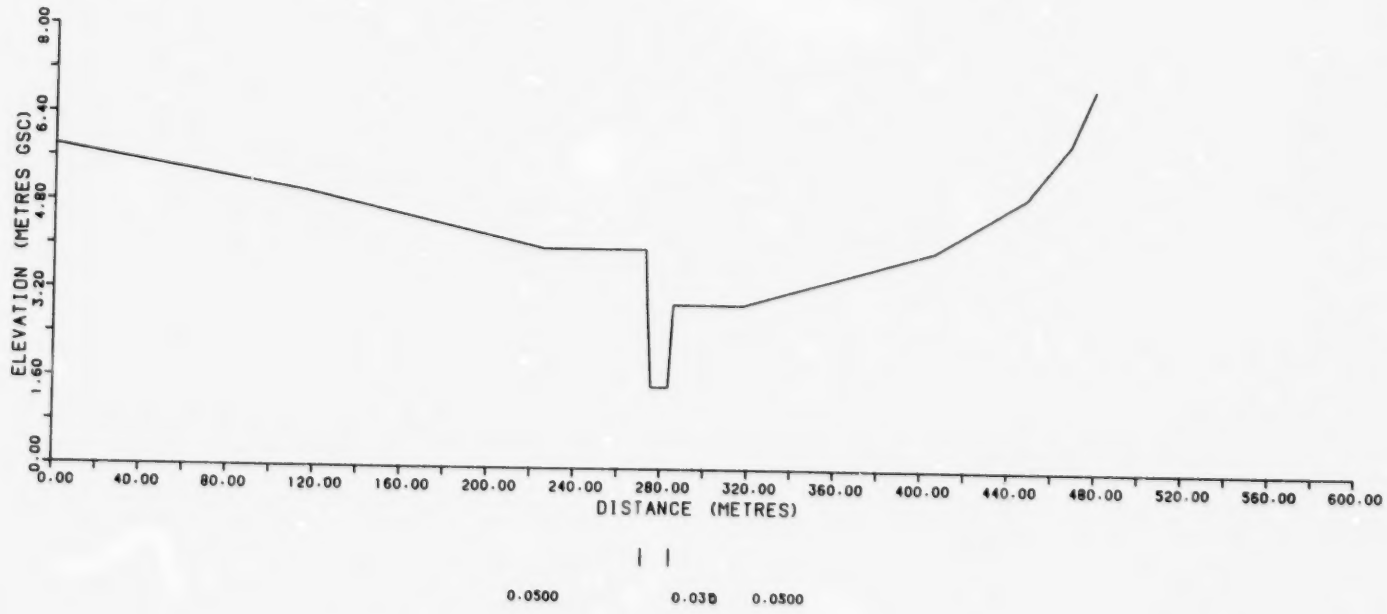

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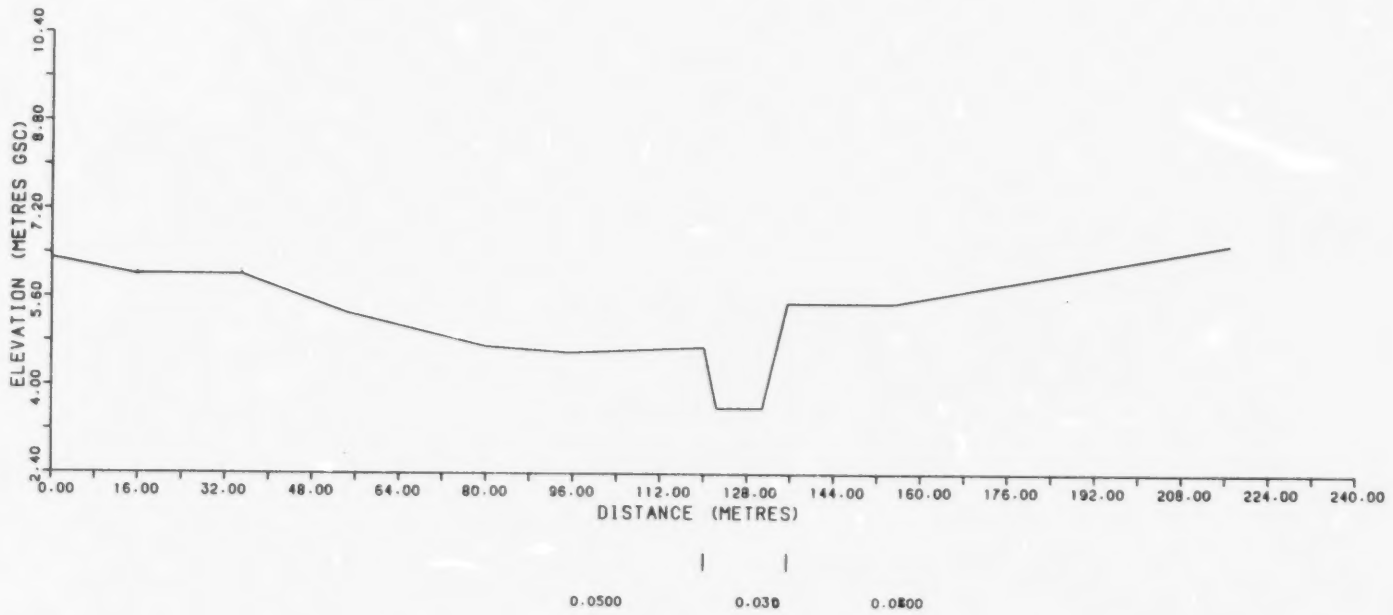

BRIERLY BROOK HEC-2 MODEL

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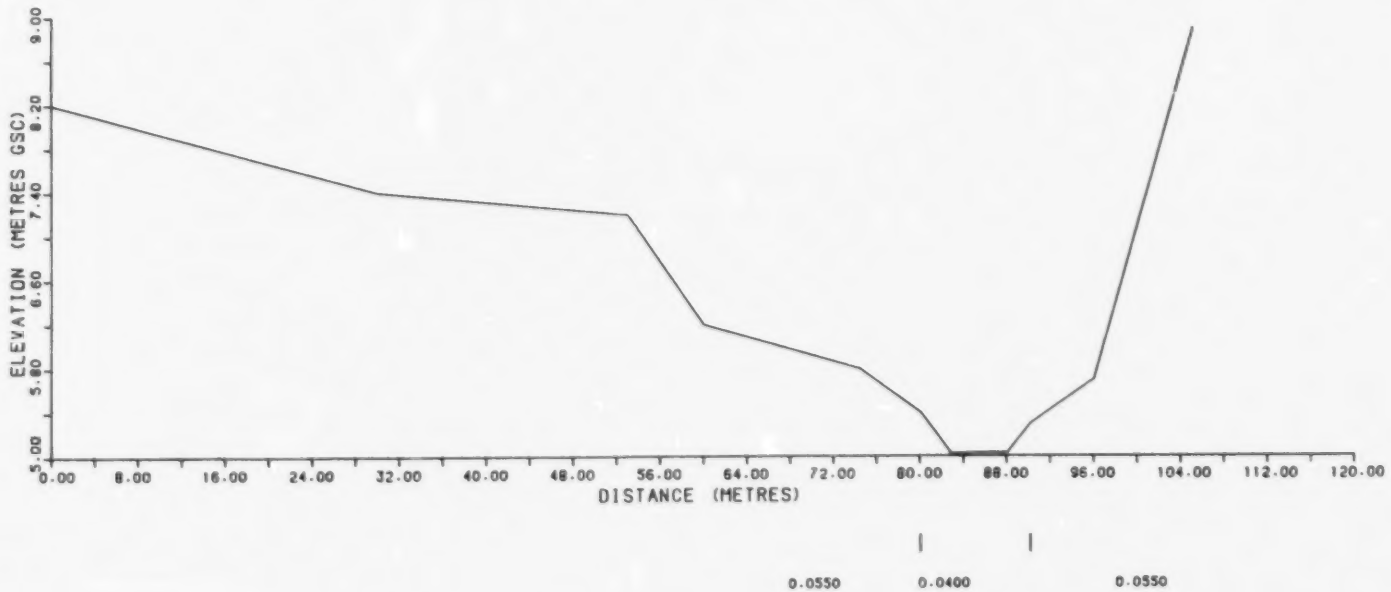

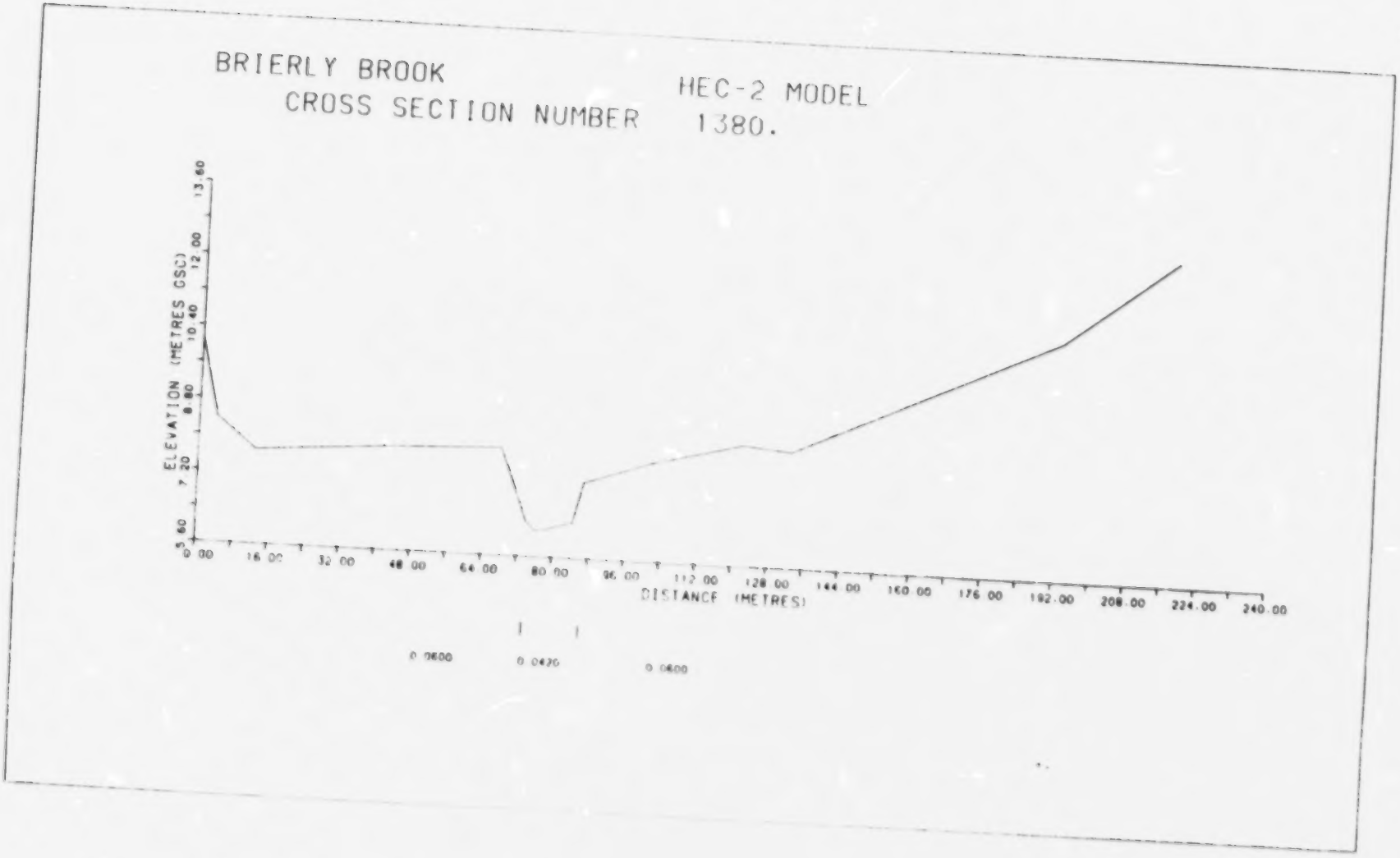
BRIERLY BROOK
HEC-2 MODEL
CROSS SECTION NUMBER 1380.
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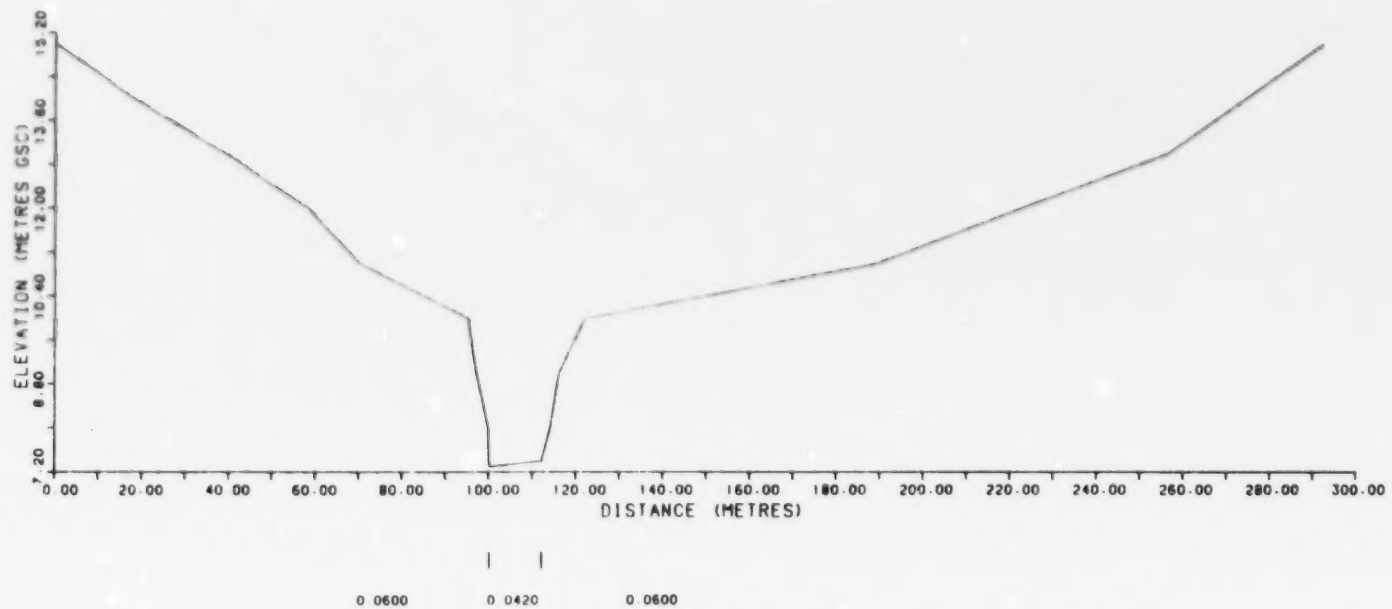
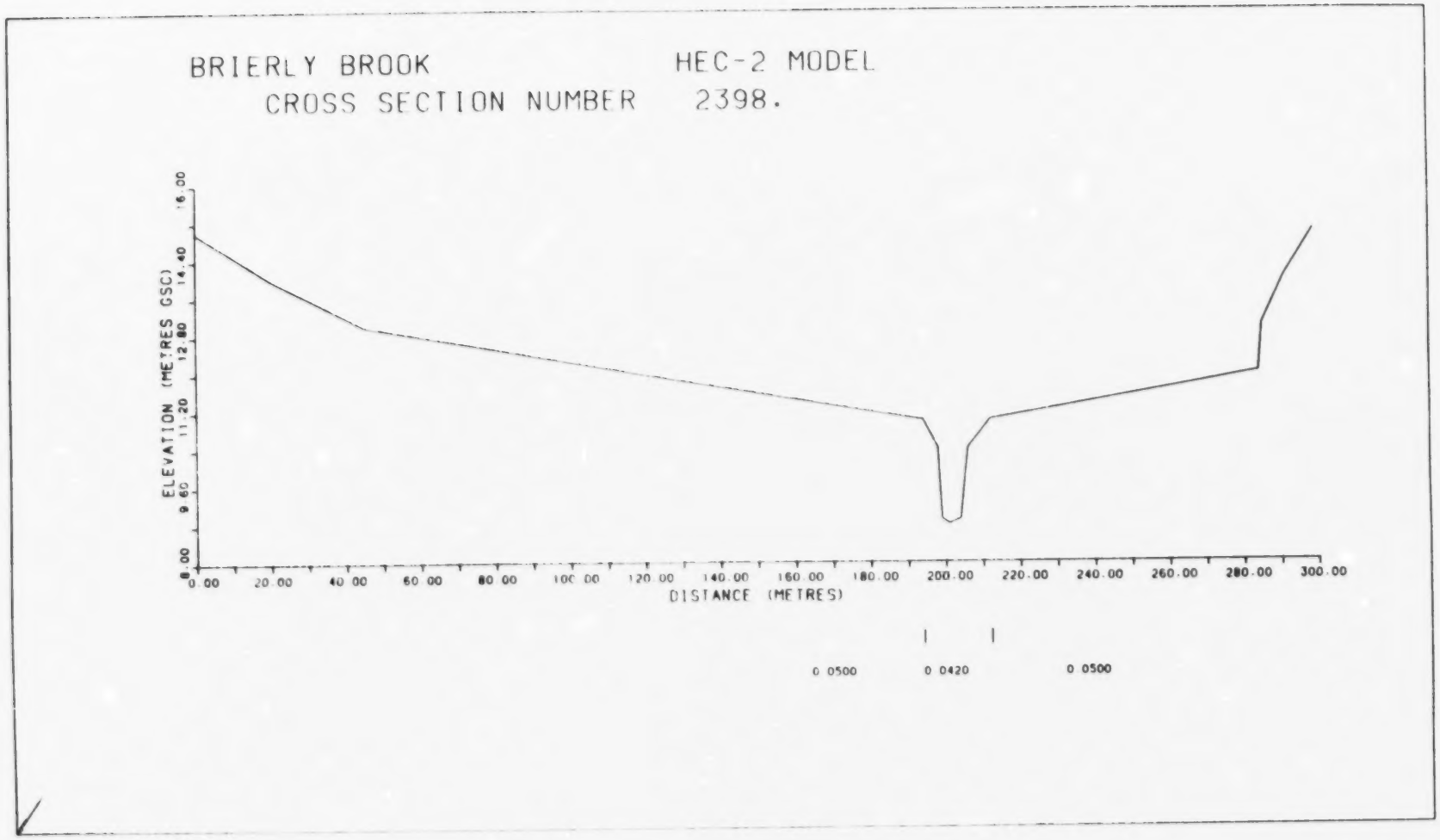
7.20
8.80
10.40
12.00
13.60
0.00
16.00
32.00
48.00
64.00
80.00
96.00
112.00
128.00
144.00
160.00
176.00
192.00
208.00
224.00
240.00
DISTANCE (METRES)
0.0600
0.0420
0.0600

BRIERLY BROOK HEC-2 MODEL

CROSS SECTION NUMBER 1727.




BRIERLY BROOK HEC-2 MODEL
CROSS SECTION NUMBER 2398.
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9.60
11.20
12.80
14.40
16.00
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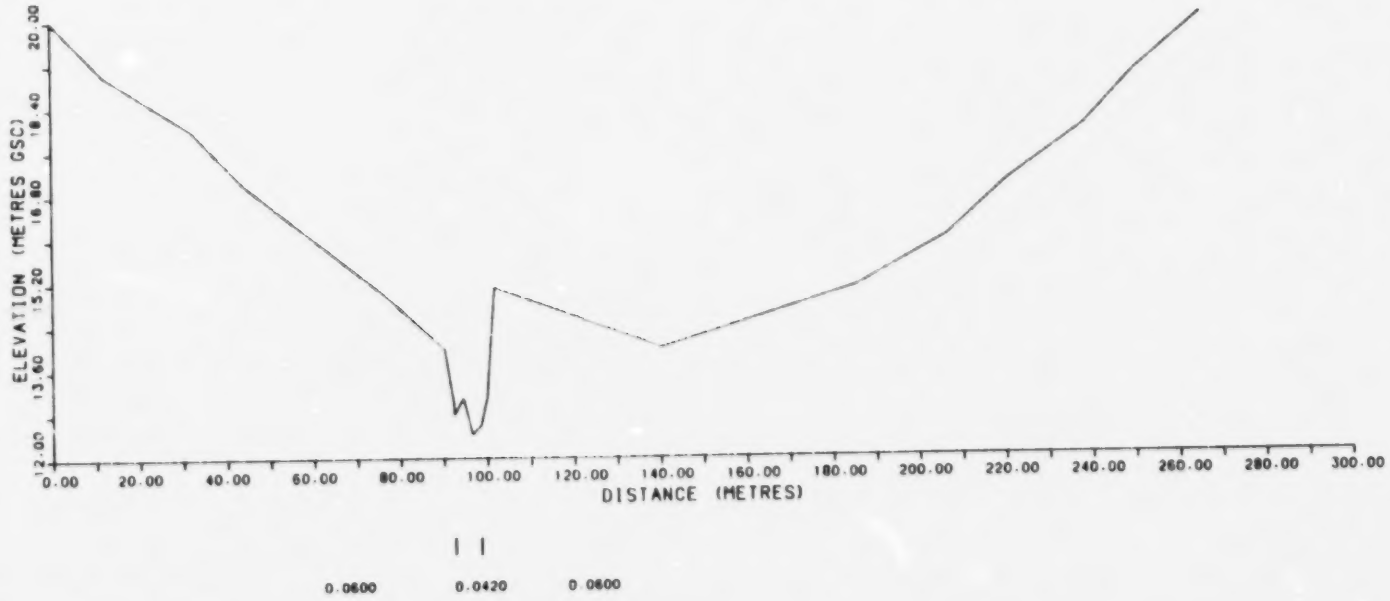
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00
240.00
260.00
280.00
300.00
DISTANCE (METRES)
0.0500
0.0420
0.0500

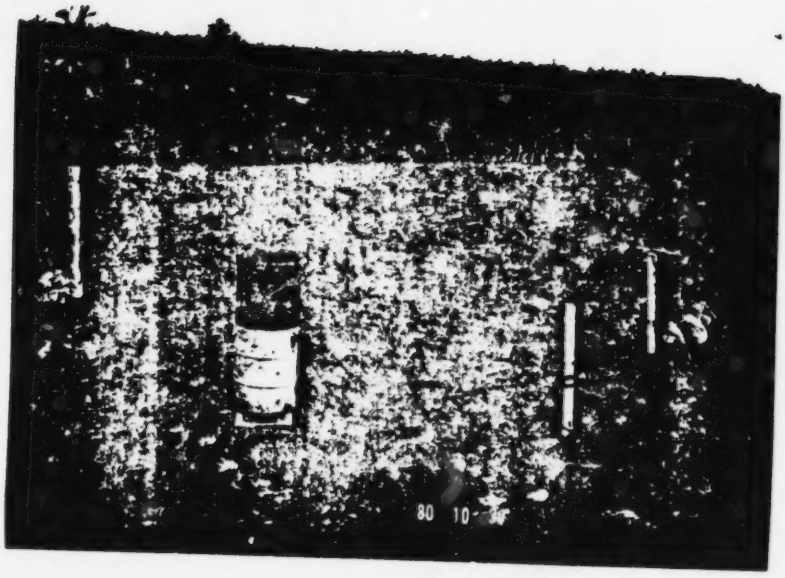
BRIERLY BROOK HEC-2 MODEL

CROSS SECTION NUMBER 3267.



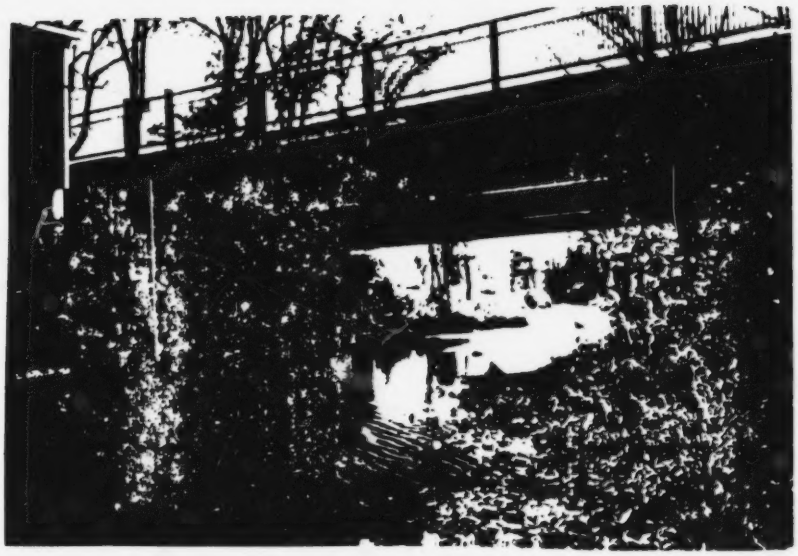
appendix d

TYPICAL FIELD MONITORING
INSTALLATIONS



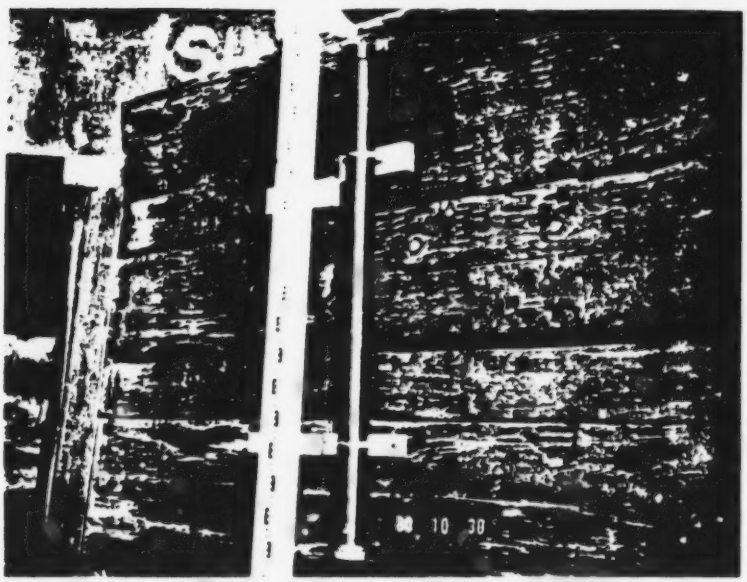
Tipping Bucket Rain Gauge near
Brierly Brook and Somers Road

Flow Metering Installation on
Brierly Brook and Somers Road (B-6)



Staff Gauge on Brierly Brook

at Main Street Bridge (B-3)



Staff and Crest Gauges on

Brierly Brook at Braemore Road Bridge (B-4)

appendix e

RAIN-AND-SNOWMELT ANALYSIS

CR12-01-10

APPENDIX E

RAIN-AND-SNOWMELT ANALYSIS

E.1 General

The spring period is characterized by snowmelt and rain-on-snowmelt events. An analysis of the snow cover data for the Antigonish area reveals that snow cover normally appears in December and persists until the middle of April. Based on nineteen (19) years of snow cover data at the Antigonish Marshy Hope station, the average snow cover depth at the end of March is 58.7 cm (20.5 inches) and the snow water equivalent is 155.0 mm (6.1 inches).

This snow cover is usually available for melt in April. To compare spring and summer conditions, the snowmelt rate during the rainfall and spring rainfall-and-snowmelt "intensity-duration-frequency" curves must be determined. The following two sections deal with these determinations.

E.1.1 Snowmelt Rate During Rain

The general equation for basin snowmelt rate during rain as developed by the U.S. Corps of Engineers (Ref. 27) is,

$$M = M_{rs} + M_{rl} + M_{ce} + M_g + M_p \qquad (1)$$

with M = total daily snowmelt

M_{rs} = snowmelt by shortwave radiation

M_{rl} = snowmelt by longwave radiation
M_{ce} = snowmelt due to convective condensation
M_g = snowmelt from ground heat
M_p = snowmelt heat transfer from rain

The snowmelt components are estimated by the following equations:

$$M_{rs} = 0.00508\ R_{si}(1-a),\ \text{inches/day} \qquad (2)$$

where R_{si} = insolation, langleys/day

and a = albedo

$$M_{rl} = 0.029\ (Ta-32),\ \text{inches/day} \qquad (3)$$

where Ta = Mean Air Temperature in degrees Fahrenheit at 10 feet height above ground

$$M_{ce} = 0.045(Ta-32),\ \text{inches/day} \qquad (4)$$

for forested areas

$$M_g = 0.02\ \text{inch/day} \qquad (5)$$

$$M_p = 0.007\ P\ (Ta-32),\ \text{inches/day} \qquad (6)$$

where P = Daily precipitation, inches/day

Equations 1 through 6 will be used to estimate the snowmelt rate during spring rainfall.

E.1.3 Rain-and-Snowmelt Intensity Duration Frequency (IDF) Curves

The snowmelt rate during rain in April was computed using Equations 1 through 6 in the previous section. The meteorological input parameters to the above equations were based on the average April observations taken from Table 7.

The insolation for April was determined using an approach suggested by Meteer (Ref. 32) developed especially for Canadian conditions. Using the average April cloudless day insolation for the Kentville and Halifax stations, the insolation (R_{si}) was determined to be 128 langleys/day. The snow albedo was taken as 0.65 (Ref. 31). The final result of the snowmelt rate (M) expressed as a function of the daily rainfall (P) is,

$$M = 0.619 + 0.035xP, \text{ inches/day} \quad (7)$$
and P is in inches/day

or in metric units,

$$M = 0.656 + 0.035xP, \text{ mm/hr} \quad (8)$$
and P is in mm/hr

The maximum snow cover remaining at the end of March is 155 mm in water equivalent. This is taken as the most likely maximum snow depth available for melting in April. Hence, the total available snowmelt (m_T) during rain period (Tr) is the smaller of 155 mm and (M_xTr). In equation form,

$$m_T = \text{Min } (155, M_x Tr), \text{ mm} \quad (9)$$

where M = Potential rate of snowmelt during rain, mm/hour (from Equation 8)

Tr = Duration of rainfall, hours.

and the available snowmelt rate (m_T) during rain is,

$$m_T = m_T/Tr, \text{ mm/hr} \quad (10)$$

Consequently, for each rainfall duration Tr (hours) the April rainfall intensity P (mm/hr) was used to compute the potential rate of snowmelt M during rain, (Equation 8). Equations 9 and 10 then determine the available snowmelt rate during rain, m_T.

The sum of 'm_T' and its corresponding 'P' gives the rain-and-snowmelt IDF curves in April as shown in Figure 6-7. The above procedures assume that the recurrence interval of rainfall and snowmelt events are the same. That is, for example, a 25 year rainfall event corresponds to a 25 year rain-and-snowmelt event. Such an assumption is of course highly approximate because snowmelt rate and snow cover are highly variable. The rain-and-snowmelt IDF curves in April was developed here primarily for the purpose of comparing with the annual rainfall IDF curves for the September-December period.

appendix f

DRAWING OF
BRIERLY BROOK DAM

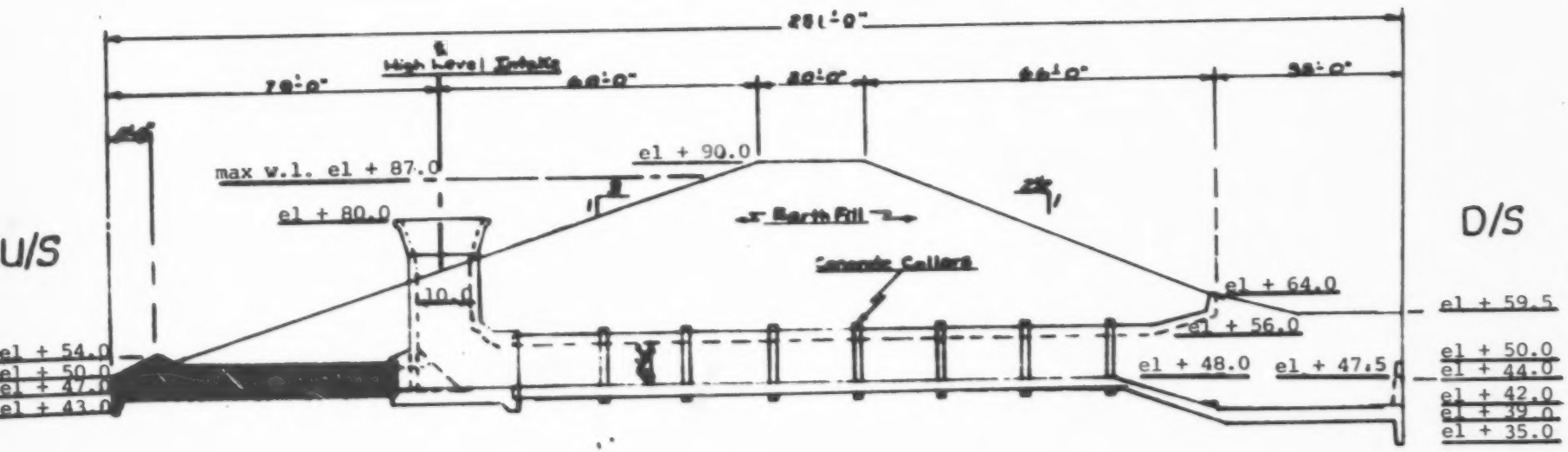


FIGURE F-1

BRIERLY BROOK DAM
(Not to Scale)

Note: All dimensions are in feet
Source: Maritime Resource Management Service

appendix G

1:20 AND 1:100 YEAR
COMPUTED WATER SURFACE ELEVATIONS
FOR BRIERLY BROOK
AND
WEST AND RIGHTS RIVERS

TABLE G-1

COMPUTED WATER SURFACE ELEVATIONS
FOR LOWER REACHES OF WEST AND RIGHTS RIVERS

Cross Section	20 Year Water Surface Elevation (m)	100 Year Water Surface Elevation (m)
0	1.80	2.19
200	1.80	2.19
600	2.28	2.59
850	2.50	2.83
922	2.56	2.89
948	2.70	3.14
1008	2.78	3.22
1088	2.88	3.32
1208	3.09	3.56
1388	3.32	3.78
1468	3.40	3.88
1528	3.54	4.04
1608	3.44	4.05
1623	3.47	3.97
1638	4.27	4.96
1668	4.38	4.99
1728	4.48	5.08
1860	4.57	5.16

Note: 1:20 and 1:100 Year Tide Levels Govern for Cross-Sections 0 to 200.

TABLE G-2

COMPUTED WATER SURFACE ELEVATIONS
FOR THE RIGHTS RIVER

Cross Section	20 Year Water Surface Elevation (m)	100 Year Water Surface Elevation (m)
1860	4.57	5.16
2211	5.36	5.70
2340	5.63	5.97
2450	5.70	6.01
2514	6.01	6.43
2618	6.77	7.27
2664	6.80	7.33
2684	7.21	7.37
2702	7.61	8.50
2724	7.82	8.59
2762	7.82	8.60
3020	8.00	8.70
3200	8.49	9.00
3370	9.10	9.48
3515	9.60	10.02
3678	10.02	10.29
3780	10.81	11.11
3850	12.73	13.49
3920	12.86	13.63
4048	12.99	13.75
4208	13.50	14.01
4328	13.86	14.26
4342	13.96	14.35
4442	14.38	14.68
4557	15.60	16.03
4772	16.50	17.00
4857	16.90	17.38
4893	17.24	17.79
4982	18.10	18.69
5002	18.16	19.69
5097	18.51	19.62

TABLE G-3

COMPUTED WATER SURFACE ELEVATIONS
FOR THE WEST RIVER

Cross Section	20 Year Water Surface Elevation (m)	100 Year Water Surface Elevation (m)
1860	4.57	5.16
1893	4.59	5.17
1943	4.60	5.19
2063	4.63	5.21
2263	4.68	5.27
2438	4.88	5.40
2648	5.02	5.54
2908	5.34	5.75
2954	5.42	5.80
2969	5.18	5.46
2981	5.53	6.57
2996	6.44	7.78
3052	6.48	7.79
3267	6.57	7.83

TABLE G-4

COMPUTED WATER SURFACE ELEVATIONS
FOR BRIERLY BROOK

Cross Section	20 Year Water Surface Elevation (m)	100 Year Water Surface Elevation (m)
0	4.59*	5.17*
20	4.59*	5.17*
102	4.59*	5.17*
162	4.59*	5.17*
222	4.59*	5.17*
300	4.59*	5.17*
317	4.59*	5.17*
332	4.59*	5.17*
345	4.59*	5.17*
360	4.59*	5.17*
379	4.59*	5.17*
457	4.66	5.17*
498	4.77	5.17*
530	5.05	5.17*
560	5.08	5.19
589	5.11	5.23
604	5.19	5.43
619	5.36	5.55
629	5.38	5.57
644	5.41	5.61
667	5.48	5.69
720	5.77	6.01
765	5.83	6.05
862	6.08	6.32
878	6.31	6.49
895	6.65	6.82
905	6.67	6.84
910	6.68	6.86
939	6.73	6.92

* Backwater Effect from the West River

TABLE G-4 (cont'd)

COMPUTED WATER SURFACE ELEVATIONS
FOR BRIERLY BROOK

Cross Section	20 Year Water Surface Elevation (m)	100 Yeawr Water Surface Elevation (m)
1083	6.94	7.20
1380	7.44	7.67
1560	8.20	8.43
1660	8.38	8.59
1705	8.51	8.67
1727	8.62	8.76
1737	8.65	8.81
1748	8.67	8.83
1898	9.43	9.58
2028	9.64	9.85
2178	9.96	10.25
2398	11.10	11.38
2623	11.80	12.06
2673	12.16	12.31
2728	12.41	12.61
2868	12.71	12.99
3028	13.03	13.28
3233	13.59	13.83
3267	13.62	14.25
3277	13.85	14.25
3317	14.15	15.00
3402	14.18	15.01
3525	14.44	15.00
3755	15.13	15.62

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